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Effects of Regular Use of Scalable, Technology Enhanced Solution For Primary Mathematics Education

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ABSTRACT

Mathematics is one of the key subjects in any school curriculum and most teachers agree that mathematical skills are important for students to master. There is an abundance of research in learning mathematics and a consensus exists among researchers that technology can enhance the learning process. However, many factors need to be taken into consideration when introducing technology into teaching mathematics. Developing a more natural collaboration between learning technology experts, teachers, and students ensures all stakeholders are considered. Involving teachers early on helps develop enduring commitment to innovations and practical solutions. Moreover, creating a culture of collaboration between experts in the field and teachers brings to bear the best of what both worlds have to offer.

This thesis synthesizes six papers and offers additional findings that focus on how technology experts can collaborate with elementary teachers to improve student learning outcomes. We focus on managing educational change in ways that improve the sustainability of innovations. We also explore how technical and teaching experts co-create effective lesson plans. In one of the six papers we collected and reported teachers' responses to survey questions covering typical usage patterns on a platform. Teachers' direct feedback was collected and incorporated to improve technical solutions. Moreover, one study was conducted abroad to measure the effect of culture on the teaching and learning process.

Evidence of effectiveness of technologically enhanced lessons and corresponding homework was based on multiple studies in grades 1 - 3, covering 379 students. The effectiveness of educational technology was measured based on two variables: student performance in mathematics, based on the learning objectives specified in the curriculum, and arithmetic fluency measured by how rapidly and accurately students solved basic arithmetic operations. Statistically significant findings show that educational technology can improve two target variables when comparing students who did not use educational technology to students who did. An additional effect size analysis was conducted to verify and compare results with previous

research. Based on these results, platform use produced the same or better effect than previous studies.

Based on teacher feedback and user growth on the platform, we managed to integrate technology into the regular school classroom in meaningful and sustainable ways. We were clearly able to support teachers in their practice in a manner that resulted in noticeable student achievement gains. A survey revealed a need to emphasize new features that were introduced to the platform in teacher training programs. Teachers also reported having a positive attitude towards the platform and the initiative gained wide acceptance among their peers.

TIIVISTELMÄ

Matematiikka on yksi tärkeimmistä kouluaineista pelkästään tuntimääräisesti mitattunakin. Matematiikan osaamista ja oppimista pidetään yleisesti tärkeänä ja arvostettuna taitona. Matematiikan oppimisesta on valtavasti tutkimusta ja tutkijoiden keskuudessa vallitsee yhteisymmärrys tietotekniikan positiivisista mahdollisuuksista edistää matematiikan oppimista. Tietotekniikan ja oppimisen vuorovaikutus on kuitenkin monisyinen vyyhti ja sen onnistunut hyödyntäminen vaatii tutkijoiden, opettajien ja oppilaiden välistä tiivistä ja vuorovaikutteista yhteistyötä. Uusien innovaatioiden ja kokeilujen onnistumiselle ja niihin sitoutumiselle luodaan vahva pohja, kun opettajat otetaan mukaan kehitystyöhön ensimetreiltä lähtien. Tällaisen tiiviin yhteistyökulttuurin vaaliminen mahdollistaa käytännön työn ja teorian vahvuuksien hyödyntämisen.

Tämä väitöstyö koostuu kuudesta artikkelista. Artikkelit kuvaavat, kuinka tutkijat ja opettajat työskentelivät yhdessä parantaakseen oppilaiden matematiikan oppimista. Tavoitteenamme oli muuttaa koulun käytänteitä pitkäjänteisesti ja kestävällä tavalla. Tutkimme kuinka tutkijat ja opettajat pystyivät yhdessä luomaan onnistuneita ja tehokkaita oppimiskokonaisuuksia. Opettajat olivat koko ajan kehitystyön keskiössä. Yhdessä kuudesta artikkelista tutkittiin kyselytutkimuksen avulla opettajien kokemuksia ja käyttötottumuksia. Näitä vastauksia hyödynnettiin teknisessä kehitystyössä ja hyvien käytänteiden hiomisessa. Yksi väitöskirjan tutkimuksista tehtiin ulkomailla opetus- ja oppimiskulttuureista vaikutusten huomioimiseksi.

Sähköisten oppituntien ja kotitehtävien vaikuttavuuden arviointi perustuu useisiin 1.-3. luokilla tehtyihin tutkimuksiin ja kaikkiaan 379 oppilaan vastauksiin. Sähköisten oppituntien vaikuttavuutta arvioitiin kahden eri mittarin perusteella. Ensin matematiikan taitojen perusteella, eli kuinka hyvin kunkin luokka-asteen oppimistavoitteet olivat täyttyneet ja myöhemmin myös laskusujuvuuden perusteella, eli kuinka nopeasti ja tarkasti oppilaat pystyivät laskemaan peruslaskutoimituksia. Tulokset osoittavat, että opetusteknologian avulla pystytään parantamaan oppilaiden

suoriutumista edellä mainittujen osa-alueiden osalta verrattuna oppilaisiin, jotka eivät käyttäneet opetusteknologiaa. Tulokset olivat tilastollisesti merkitseviä. Näiden tulosten varmistamiseksi laskettiin vaikuttavuuden suuruus ja sitä verrattiin aiempiin alan tutkimuksiin. Tulosten perusteella sähköisillä oppitunneilla oli sama tai parempi vaikuttavuus kuin aiemmissa tutkimuksissa.

Opettajien palautteiden ja kasvavan käyttäjämäärän perusteella voidaan sanoa, että onnistuimme tavoitteessamme integroida opetusteknologiaa mielekkäällä tavalla osaksi koulutyötä. Onnistuimme myös tukemaan ja auttamaan opettajia opetustyössään ja samalla merkittävästi parantamaan oppilaiden suoriutumista. Kyselytutkimuksen perusteella huomasimme, että uusien ominaisuuksien kouluttamiseen tulee kiinnittää enemmän huomiota. Samassa tutkimuksessa opettajat raportoivat olevansa tyytyväisiä alustaan ja sähköiset oppitunnit näyttävät saaneen vankan jalansijan suomalaisessa opettajakunnassa.

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LIST OF ORIGINAL PUBLICATIONS

P1. Kurvinen, E., Lindén, R., Rajala, T., Kaila, E., Laakso, M. J., & Salakoski, T. (2014, November). *Automatic assessment and immediate feedback in first grade mathematics*. In Proceedings of the 14th Koli Calling International Conference on Computing Education Research (pp. 15-23). ACM.

P2. Kurvinen, E., Lokkila, E., Lindén, R., Kaila, E., Laakso, M., & Salakoski, T. (2016). *Automatic assessment and immediate feedback in third grade mathematics*. In Proceedings of Ireland international conference on education. (pp. 89-94).

P3. Kurvinen, E., Kaila, E., Rautaoja, T., Laakso, M-J. & Salakoski, T. (2020). *Technology Enhanced Learning in First Grade Mathematics*. (Manuscript).

P4. Kurvinen, E., Kaila, E., Laakso, M-J., & Salakoski, T. (2020). *Long term effects on technology enhanced learning: The use of weekly digital lessons in mathematics*. Informatics in Education Volume 19, Issue 1, (pp. 51–75).

P5. Kurvinen, E., Kaila, E., Kajasilta, H., & Laakso, M-J. (2019). *Teachers' Perceptions of Digital Learning Path in Mathematics, Languages and Programming*. In 2019 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO) (pp. 643-648). IEEE.

P6. Kurvinen, E., Dagienė, V., & Laakso, M-J. (2018). *The Impact and Effectiveness of Technology Enhanced mathematics Learning*. In Proceedings of Constructionism 2018 (pp. 344-356).

CONTRIBUTIONS OF THE AUTHOR

In paper **P1** the setup of the study was designed and results analysed by me, Rolf Lindén, Erkki Laakso Mikko-Jussi Laakso. Reporting was done collaboratively by all authors.

In paper **P2** the setup of the study was designed by me and Mikko-Jussi Laakso. The data was collected by me and analysed by me, Rolf Lindén and Erkki Kaila. Reporting was done collaboratively by all authors.

In paper **P3** the setup of the study was designed by me and Mikko-Jussi Laakso. The data was collected by me and analysed by me and Erkki Kaila. The report was written collaboratively by all authors.

In paper **P4** the setup was designed by me and Mikko-Jussi Laakso. The data was collected and analysed by me and the report was written collaboratively by all authors.

In paper **P5** the survey questionnaire was designed by me, Erkki Kaila and Mikko-Jussi Laakso. The data was analysed by me and Henri Kajasilta. Reporting was done collaboratively by all authors.

In paper **P6** the setup of the study and reporting was done collaboratively by all authors. Data was collected by me and Valentina Dagienė and analysed by me.

List of Co-Authored Original Publications not Included in This Thesis

- Kaila, E. T., Kurvinen, E., & Apiola, M. V. (2019). Ethical Considerations in Learning Analytics: Ideas and Discussion. In CEUR Workshop Proceedings (Vol. 2019). R. Piskac c/o Redaktion Sun SITE, Informatik V, RWTH Aachen.
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CONTENTS

1 Introduction

Mathematics is an essential life skill for solving a myriad of real-world, mathematical problems. People use mathematics for unit conversion, making an accurate measurement, being on time, or determining the interest on a loan. In private business, data scientists use mathematics for making predictions and nurses use mathematics to deliver the right amount of medication to their patients. Mastering these skills make life much easier. Conversely, not knowing these skills might make life more complicated, ambiguous, and difficult. In this thesis, I describe how to use educational technology to motivate and engage students to improve their mathematics skills.

Against the backdrop of the last 30 years, the pace of change in the educational technology journey reveals increasingly rapid advancements. Even before access to the Internet was provided in schools, politicians and curricula designers were promoting technology in education. Only one decade ago smart phones were uncommon and now people regularly access the Internet from devices carried in purses and pockets. Recent advancements were largely driven by rapid technological advancements that have expanded to the cloud, mobile, social, and big data. These developments have only accelerated the need and desire to include technology in the teaching and learning and learning process.

The development and expansion can be seen locally in the Finnish national curriculum when comparing the curriculum from 2004 to current curriculum in 2016 (POPS, 2004; Opetushallitus, 2016). One of the biggest drivers for using technology in education has been the new matriculation examination that was conducted completely electronically for the first time in 2019. Online examinations create pressure on all schools to prepare students to be capable of utilizing digital tools, locally and around the world.

Globally, for example, the National Council of Teachers of Mathematics (NCTM) recognize the usefulness and effectiveness of integrating technology into mathematics education. *"It is essential that teachers and students have regular access to technologies that support and advance mathematical sense making, reasoning, problem solving, and communication. Effective teachers optimize the potential of technology to develop students' understanding, stimulate their interest, and increase their proficiency in mathematics. When teachers use technology strategically, they can provide greater access to mathematics for all students."* (NCTM, 2011, p. 1). The key words in this statement are *regular access* and *use technology strategically*. These are also the foundation for our work. How can we achieve meaningful tools that can integrate into the regular work of teachers?

Several studies show the possible positive impact technology can have on student learning (eg. Cheugn & Slavin, 2013; Harskamp, 2014; Brasiel, et al. 2016; Chauhan, 2017). However, in practice, greater use of technology by students and positive student outcomes is not straight forward. The OECD published a report in 2015 suggesting a positive correlation does not exists between ICT usage and student test scores on the Programme for International Student Assessment (PISA). Student results were widely reported in the Finland media stating that there is no evidence that expensive Information and Communication Technologies (ICT) equipment provides positive impact on student learning results (e.g. Hiiro, 2015).

The juxtaposition shows that technology is a necessary but insufficient condition for student learning and must be supported by several other factors. It matters which technological tools are available, how they are used, and what kind of content is available for students. Like any other tool or methodology, technology is likely to provide positive benefits only if it is used correctly and in a meaningful way. For this, teachers need training and support and the whole educational field needs to have the best practices from the academic community.

In addition to improving learning performance, we should discuss other benefits that technology can provide. Digital materials can substantially reduce the time used distributing content to students. Digitized information is easier to store, access and transmit, and digitization is not fixed in the way that texts are printed on paper. Digital materials should also be easier to customize and adapt to different needs. Many routine exercises can be automatically assessed, which drastically reduces the teacher's time when assessing, and also enables teachers to require students to practice more. Automatic assessment enables data collection from students' answers and provides learning analytics for teachers. Timely data and a more comprehensive view of students' learning process helps teachers provide better, targeted help and support (e.g. Lokkila, et al. 2015; Kanth, et al. 2018; Cai, et al. 2018). Hopefully digital tools help save teachers' scarce time and help them focus their attention where it is needed most.

In this thesis, I present how a digital learning path (later referenced as learning path or DLP) for mathematics was designed, built and implemented on top of a digital learning platform, ViLLE (Laakso, Kaila & Rajala, 2018). The effectiveness of the DLP was based on multiple studies conducted in first, second, and third grades with 379 students. We used previous knowledge from different domains such as teaching programming (Kaila, 20018; Laakso, 2011). Even after all the reported experiments were collected, the teacher feedback for making improvements continues. These studies, experiences, and feedback from teachers are discussed in more detail.

1.1 Research Questions

The goal of this thesis is to determine if education technology can be integrated successfully into mathematics education in primary education. For this purpose, we started to build mathematics content on top of a digital learning platform called ViLLE (Laakso, et al. 2018), and conducted multiple studies to discover the impact of ViLLE on students' learning performance and teachers' perceptions. The main research questions that this thesis attempts to answer are:

RQ1. Do regular technology enhanced lessons improve students' mathematical performance?

RQ2. *Do regular technology enhanced lessons improve students' arithmetic fluency?*
RQ3. *What are teachers' perceptions regarding using technology enhanced lessons?*

A technology enhanced lesson covers one weekly lesson in school where students use digital mathematical exercises and similar digital exercises for homework. The first questions answer whether or not one weekly ViLLE lesson, with interactive exercises, can improve students' mathematics performance compared to criteria set by the Finnish national curriculum in mathematics (OPS, 2016). Performance in this context means how well the students have learned the key topics required for their age in the curriculum. The null hypothesis is that there is no effect nor change in students' performance. The second question considers the speed and accuracy that students can solve basic arithmetic facts, or arithmetic fluency. Also in this question, the null hypothesis is that there is no change or effect. The third question concentrates on teacher perceptions on ViLLE and the mathematics content developed on top of ViLLE (the learning path).

1.2 Methodology

The methodology of the research reported in this thesis is divided into two categories. First, the whole development progress from 2012 to 2018 is best described as an action research. Second, the result step in action research is best described by Quasi-Experimental research (QE). QE is discussed separately, in more detail, because the results step plays a crucial role in answering the research questions of this thesis.

1.2.1 Longitudinal Action Research

Avison, Lau, Myers & Nielsen (1999) said: "*To make academic research relevant, researchers should try out their theories with practitioners in real situations and real organizations.*" For this reason the DLP was developed in close collaboration with teachers. When the experiment started, the structure and the content were not fixed nor ready and the idea was to create them together with practitioners. This collaboration between researcher and practitioner is one of the key traits of action research (Adelman, 1993).

Action research is not one methodology but it is a set of different methodologies in the research tradition. In addition to different methodologies, action research may also differ in the emphasis on its steps. (Dickens & Watkins, 1999).

We use the steps, **planning**, **action** and **results** (Figure 1) defined by Kurt Lewis (1946). Typically, there is an observation step between action and result but in our research the action observation occurs simultaneously and repeatedly during the cycle (e.g. Dickens, et al. 1999).

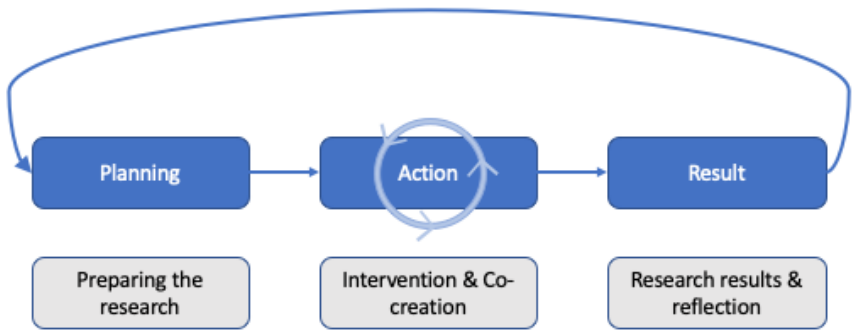

Figure 1: Action research cycle describing the process implemented in the development of the DLP.

The timeline of the development of the DLP is described in Figure 2. Each step in the timeline can be described by the action research cycle (Figure1). First, the research project starts with preparations and planning followed by intervention in class and co-creation of the content with teachers. The action cycle is described in more details in chapter 3.2.1. Finally, the action research cycle is concluded with a scientific publication analysing the impact of the intervention. In our model the action and result steps have the most emphasis. This cycle is then repeated over time and the focus is shifted from the technical development of the platform in the first studies to content creation and later on to more fine grained details like differentiation and more advanced learning analytics.

In the research presented in this thesis, the planning or action steps were not systematically documented but enabled researchers to make rapid changes to the treatment during the experiment. For example, in P1 we started with two different exercise sets, one for school and one for homework. By combining both sets into one, we managed to increase students' activity substantially. In P1, P2, P3 and P4 we were still creating the content on a weekly basis in collaboration with the teachers.

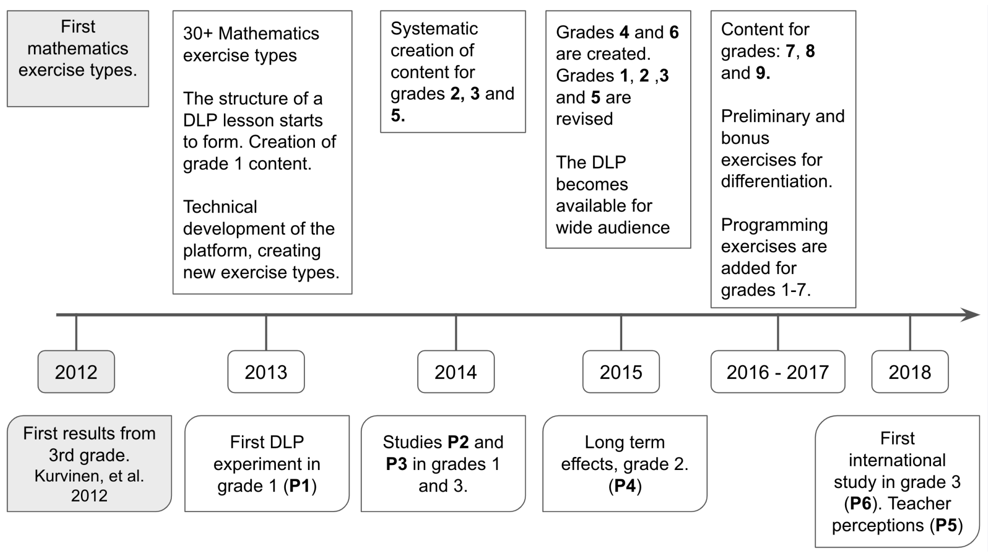

Figure 2: Timeline for creating and conducting research on the DLP.

Figure 2 gives the outline of the development process of the DLP and when the studies included in this thesis (P1-P6) were conducted. The whole process is described in more details in chapter 4.3.

1.2.2 Evaluating the impact

The classroom context naturally contributes certain limitations in regard to our research. The randomisation of students becomes difficult, if not impossible. The presence of a researcher may change teacher behavior. The number of students in each class may vary, and the number of classes in a school, or schools may not be equal. Considering this, the basis for the research was Quasi-Experimental research (QE). QE is used when random assignment is not possible or practical (Gribbons & Herman, 1997).

There are three commonly used types of QE designs listed by Gribbons & Herman (1997):

1. Nonequivalent group;
2. posttest only, nonequivalent group pretest-posttest;
3. and, time series design.

All the studies included in this thesis follow the QE design, except for P5, which was survey method research. Table 1 summarises the methodology used in each paper and which research question they answer.

Table 1: Methodology used in papers P1-P6

Paper	Setup	RQ
P1	Pretest-Posttest	RQ1
P2	Pretest-Posttest	RQ1
P3	Pretest-Posttest	RQ1, RQ2
P4	Posttest	RQ1, RQ2
P5	Survey	RQ3
P6	Pretest-Posttest	RQ1, RQ2

In a posttest only design, the impact is measured after a treatment. This design does not take into account the fact, that there could be a big difference between the group’s performance before the treatment began. The posttest only design was solely utilized in P4.

Pretest-posttest design monitors the level of the groups before the treatment. This enables researchers to rule out the initial differences between groups. Pretest-posttest design was used in P1, P2, P3 and in P6.

In a time series design, there are multiple measurements before and after the experiment. In P3, we conducted an additional measurement during the experiment, but no additional tests were conducted before pretest, or after posttest, hence the research design was not a time series design.

By using pretest-posttest design, the researcher can measure the performance of groups before and after the experiment. However, this does not eliminate other factors that might affect the result such as the teacher, the motivational impact of participating in a research, or parents' influence. By conducting a similar study in multiple settings, observations of impact in different conditions helps eliminate the impact of factors that are difficult to rule out in a single setup. Acampora & Boissoneau (1995) suggest that even experimental design has a problem similar to QE, where a positive result does not "prove" or "confirm" the result, rather it tests the theory and it escapes being disconfirmed.

P5 was a survey research for which teacher feedback of using the DLP was collected. The paper presented quantitative analysis of teachers' answers in various fields. Examples include: how often teachers utilized DLP, which features were used, and how often they assigned homework. There were also questions concerning the quality of exercises. In addition to quantitative analysis, there were multiple open questions that allowed for more in-depth opinions from teachers.

1.3 The Structure of this Thesis

The opening chapter provides necessary background information for considering a paper that synthesizes six related papers on education technology as a tool for improving student learning. Next, a review of related literature in the field of technology in education is presented. Third, an introduction to ViLLE describes the digital learning platform on which the research is based and the learning path were built. Fourth, the main principles of the learning path and the development process with teachers are introduced. Fifth, an analysis is presented in the form of calculating the effect sizes of previous studies. Next, a synthesis combines the results of prior research studies. Last, the thesis answers the research questions and suggests the need for future work.

Six research papers, reporting the impact of ViLLE on students' mathematics performance and teachers' perceptions, serves as the basis for this paper. Research papers P1, P2, P3, P4 and P6 contribute to RQ1 and investigate whether technology enhanced lessons improve students' mathematical performance. Research papers P3, P4 and P6 also address the RQ2, the impact of technology enhanced lessons on students' arithmetic fluency. Finally, the P5 addresses RQ3, teachers' perceptions regarding technology enhanced lessons.

P1 was the first time the DLP was introduced in a classroom setting. It presented the first findings on grade 1 student perceptions and impact on learning performance (7-year-old students). P2 was similar to P1 and focused on third grade (9-year-old students) for a longer time period. P6 involved a similar setup with one change; researchers did not influence the Lithuanian third grade students. P5 survey research gathered teachers' perceptions of the DLP. P4 reported posttest results after using DLP for two years. In P3, we reported results after using DLP for one academic year in first grade. The study also included a third test in the middle of the experiment.

2 About Educational Technology and Mathematics: Related Studies and Applications

Related literature in educational technology is expanding and the terminology used to address technology in education is becoming less precise. Educational technology is the use of hardware and software to facilitate teachers managing processes and student learning. It encompasses several domains and enables a variety of educational approaches. Technology for education includes devices and games, applications and platforms. However, this expansion has not come without a price. Researchers in the field may not be aware of advances by other researchers. Two overcome this a more interdisciplinary approach is needed.

Common terminology used in the field is introduced, and the rationale for choosing Technology Enhanced Learning (TEL) for this thesis is explained. Computer Assisted Learning (CAL) describes the use of computers, as in devices and software, to enhance learning by providing instructions, drilling and exercises (Lai, et al. 2015). We have used CAL in previous research papers instead of TEL. Based on Google Scholar search, CAL seem to be tightly associated with language learning via Computer-assisted language learning (CALL).

Another similar term is Computer Assisted Instruction (CAI). Based on Google Scholar search results, this seems to be one of the oldest concepts to refer to using educational technology. Our search yielded results all the way from the 60's to the present day. Harskamp (2014) defines CAI as a computer software that helps students learn or provides opportunities to practise skills.

Both definitions for CAL and CAI seem similar. However, there are reasons to avoid using these concepts. Using the term ″computer″ places emphasis on a device used to access software. We argue that this is conceptually limiting, considering the first association is a big gray box, when nowadays it is more common to use a laptop, tablet, and mobile phone. The word, "instruction" can also be problematic. Instruction is a narrow term, due to the emphasis on delivering the message instead of the possibility of practicing, making mistakes, and trying to overcome those mistakes. "Learning" offers a much broader view of the possibilities of technology.

Blended Learning (BL) has gained popularity but it refers to listening to a traditional lecture in combination with distance learning rather than in-class technology usage. BL is also typically associated with higher education rather than with primary education (Graham, 2013; Cummings, et al. 2017).

Technology Enhanced Learning (TEL) is a rather new term and it is widely accepted in Europe and especially in the UK. It has replaced popular terms such as e-learning, learning technology, and computer based learning (Bayne, 2015). The "technology" in TEL expands the range of technologies beyond CAI and CAL by referring to more devices than just computers. The word "enhanced" in TEL is more problematic in research. It has clear prejudice in favour of the impact of technology. On the other hand, in many cases research is conducted in order to improve something. For me it describes the objective. It would be even unethical to conduct research that would not aim for enhancement. Kirkwood & Price (2014) raise the question about what is being enhanced. Is it one or more of the following: improvements in assessment scores, self-efficacy of the students, improvement of teaching or something else? In this thesis, there are actually two goals. One goal is to improve students' performance that could be measured in improved assessment scores. Another is to help teachers improve their teaching. Moreover, "learning" in TEL is problematic because sometimes we actually mean "teaching" instead of "learning" (Bayne 2015). This is also true in case of this thesis. I argue that learning is a complicated process and is dependent on teaching. If we can improve teaching, it will also enhance learning.

There are several technological tools to support student learning in mathematics. Tools include physical calculators, digital calculators, simulations, advanced 2D/3D drawing platforms, and tools that help to write formulas on keyboard. This thesis concentrates on digital alternatives that supplement or replace the pen and paper method of practicing.

There seems to be a general consensus among researchers that TEL has a positive impact on learning performance. The impact has been shown multiple times by multiple meta-analysis, and the implications can be seen in practice, for example, in the NCTM (2011) statement presented in the introduction of this thesis (eg. Kulik & Kulik, 1991; Vogel & Vogel 2006; Li & Ma, 2010; Cheung & Slavin, 2013; Chauhan, 2017). However, the conclusion is not straight forward, and learning cannot be automatically improved by just introducing technology. There are mixed results, where learning results have not improved and might have even declined after introducing technology (eg. OECD 2015; De Witte, & Rogge, 2014; Campuzano, et al. 2009). These examples are discussed in detail later.

Meta-analyses in the field of TEL are generally criticised by the fact that there might not be a willingness to publish null results or even negative results, which would make the meta-analysis biased towards the positive. Chauhan (2017) overcomes this limitation by calculating a failsafe number, which shows how many null result publications would be needed to nullify the results. Cheung et al. (2013) raises another concern about the validity of many studies. There are multiple reports that don’t have a control group, have a great difference in pretest or cover only a short duration. Another factor to consider is the scope of the meta-analysis. How the research articles have been filtered, do they cover multiple subjects or do they concentrate on for example in mathematics. Some reports concentrate on games, while others include a wide variety of applications.

Chauhan (2017) concentrates their study on elementary level education, including 122 peer-reviewed publications. The analysis contains multiple subjects and Chauhan makes a distinction of TEL effectiveness between different subjects. High effectiveness was found for general subjects and science while mathematics, languages, and science & technology had medium effect. Social studies had a low effect. General subjects in this case measured TEL that was used in more than one subject. The overall effect size reported was 0.546 (0.469 for mathematics). A similar primary focused study was conducted by Harskamp (2014). They included only 16 studies and found an overall effect size of 0.48. Both previous results seem quite high compared to effect size of 0.15 reported by Cheung et al. (2013). Their report covers only mathematics applications in K12 with 45 elementary studies and 29 secondary studies. In a similar K12 study, Li et al. (2010) report an effect size of 0.28. They reported 46 elementary studies and 37 secondary studies. The difference could be explained by TEL, having greater effect on elementary level compared to secondary level (Harskamp 2014). According to Cheung et al. (2013) there is indeed a difference between elementary and secondary studies, but the difference in their study was statistically insignificant.

Overall results from meta studies show low to medium positive effect for learning (Cohen, 1992). The previously mentioned studies have a distinctive approach that yield other interesting results regarding TEL's effects. Li et al. (2010) made an important observation and suggested that the way TEL is integrated into the classroom explains the different effect. TEL has greater impact if it is combined with a constructivist approach (student centered) rather than traditional approach (teacher centered). In light of this observation, the pedagogical approach on how TEL is introduced is something that should also be in focus.

Harskamp (2014) focused on different mathematic sub-domains and the effect of TEL in each. Selected sub-domains included: number sense, number operations, geometry/measurement, and word problems. They conclude that TEL had a similar positive effect in all domains. This is an important aspect when considering which fields of mathematics could utilize TEL. This finding provides encouragement that TEL can be utilized in all sub-domains of mathematics in a beneficial manner, with pedagogical fidelity.

Cheung et al. (2013) raise time usage as one of the factors in their analysis. According to Slavin and Lake (2008) TEL seems to be the most effortless way of improving mathematics learning results compared to changing curricula or practices in a classroom between teachers and students. In some cases, students have been involved with TEL for only 30 minutes per week. The findings from Cheung et al. (2013) support this claim. According to their findings, TEL has the greatest impact when it is utilized for 30-75 minutes rather than 30 minutes or less and 75 minutes or more. This outcome also shows that using too much TEL for one thing, might yield unfavourable results. Brasiel, et al. (2016) results support these findings. In their 11-platform comparison study, there was a clear advantage for students who used the platform as instructed. This might also mean, that other students did not use the platform, hence the result would only indicate the platform did not integrate well in practice.

A last consideration is the vast number of TEL solutions available. It is easy to fall into apples to oranges comparisons. This is important for stakeholders who make decisions regarding which TEL solutions should be introduced in schools. Li et al. (2010) has the most distinctive categorisation from above mentioned meta studies. They categorise TEL solutions as: (a) tutorial, (b) communication media, (c) exploratory environment, (d) tools, and (e) programming languages based on work (Lou, et al. 2001). Harskamp (2014) uses the same categorisation but includes only (a) and (c) for their study. The separation is not always clear, and sometimes a TEL solution might fall into two or more categories. The closest category for the DLP built on top of ViLLE is category (a), tutorials. It is defined as follows: "Tutoring programs are used to directly teach students by providing information, demonstration, and practice opportunities". Communication media includes email, chat applications, and video conferencing. Exploratory environments empower discovery, examples include Minecraft. Word processing, spreadsheets and similar fall into tools, and, for example, Scratch and similar belong in the programming category (Lou, et al. 2001). Even with this kind of categorisation, there is still a wide variety of possibilities in each group. In Li et al. (2010), Tutorial was the most common category (57 studies) and had second highest average effect size of 0.68. Exploratory environments had the highest average effect size of 1.32, but only included 9 studies. Harskamp (2014) also concluded that Tutorial solutions are more common than explorative. They do not really compare the differences in effect size between the categories, but mention that explorative environments have shown great potential. Based on my experience, explorative environments are more demanding to integrate into classroom education, which might explain their low frequency in studies.

Despite a general consensus regarding the usefulness of TEL, there are still mixed results on the impact of TEL – it has not been able to improve learning results in all cases. These are important reports, and we need to evaluate why in these studies TEL did not contribute to improved learning outcomes, and can we identify any success factors. OECD report (2015) gained visibility in Finnish media (e.g. Hiiro, 2015) when they reported that TEL usage did not show any improvements in PISA results. It is normal that standard tests yield lower results than non-standard tests (Li, et al. 2010), but De Witte et al. (2015) did show positive impact in TIMSS (Trends in International Mathematics and Science Studies) for TEL. Although, when they considered other factors in addition to TEL impacting the results, the difference was not statistically significant. In both studies, it is difficult to assess the actual level of TEL used in schools. Finland was reported to be one of the most ICT equipped countries in Europe. Still, the actual usage level was reported to be very low (Wastiau, et al. 2013). This apparent contradiction could be due to lack of training, but it also could be that Finnish teachers are not willing to use technology, if they don't see how it can benefit their job. It is also possible that the research results do not transfer well to actual school life outside the laboratory conditions when researchers are no longer the facilitators.

A two-year study, comparing 10 different programs for reading and mathematics, was conducted with more than 3000 students by Campuzano et al. (2009). The study concluded that only one product out of 10 demonstrated positive impact on the standardized test in reading. According to the report, the mathematics products were used on average 13-19 weeks out of 40 weeks of the academic year. If the average usage is divided by 13, students used the products on average 52 minutes/week. For the whole academic year, this is only 17 minutes/week. This would give a hint that the products could have been better adopted in school work. Teacher experiences could give better insight explaining these results and whether these products were successfully adopted into school work. The outcome is similar to previously discussed Brasiel, et al. (2016), which was also conducted in the United States.

Stephan (2017) conducted a one-year study on 6th graders, and compared the impact of Mathletics on their learning performance. Mathletics is quite similar to the DLP discussed in this thesis, being a supplemental mathematics platform with complete curriculum coverage. Mathletics has multiple automatically assessed exercises per topic which students can complete to practise their mathematical skills, in addition to traditional pen and paper exercises. The treatment group (N=127) used Mathletics, while the control group (N=112) did not. The impact was measured by using the state's standardised test, but no statistically significant difference was found between the two groups in regard to mathematical performance on the test. However, in the computation section, there were found statistically significant results in favor of the treatment group. Again, standardized tests typically show lower impact (Li, et al. 2010). Teachers were also interviewed and they reported finding Mathletics beneficial for classroom instruction, but reported problems with internet connectivity and availability of devices. The teachers did comment that they could utilised Mathletics more, and would have probably gained better results as a result. This shows the importance of being able to integrate to the school's workflow. Teachers also noted that a different, versatile way of practising was probably useful for students. Teachers raised many usability and versatility issues in Mathletics that might have affected how often and to what extend the platform was used. Altogether, teachers' opinions and perceptions on how students liked Mathletics were reported as positive.

3 Designing and implementing the Digital Learning Path

This chapter describes how we designed and developed the learning path for mathematics (DLP) as well as the underlying design principles of it. Before going into the details of DLP, I will first introduce my own role in the development of ViLLE and DLP and then I will proceed to introduce ViLLE. ViLLE is the platform on top of which the DLP is built. Many features from DLP have since been adopted as core features of ViLLE.

Even though I describe my role and main responsibilities in the development process, I want to emphasise that the development of the DLP and ViLLE has been and still is a team effort. When I joined the team, I started building new exercise types in ViLLE aimed for primary mathematics. The first exercise types practised decimal numbers and fractions. At first, I was the only person developing exercise types suitable for primary level mathematics. Before the first implementation of the DLP in 2013 I had already implemented more than 20 new exercise types targeted for primary level mathematics. Most of these exercise types are still in use but some have been replaced with improved versions. All of the exercises have gone through multiple development cycles by multiple developers by now.

Besides programming and creating the exercise types I was also responsible for the content creation and collaboration with teachers. In 2014 another person joined our team and we started to share the responsibility of content creation between us. While the team grew in size I was the head of the team working on mathematics DLP. In 2015 we had multiple people working on the DLP creating new content and creating new exercise types required to create diverse content for multiple grade levels. In 2017 we had all nine primary school levels available for all ViLLE teachers. In the final research article P6 we did not observe the lessons or create new content but used the translated version of the 3rd grade mathematics.

3.1 ViLLE

ViLLE is a digital learning platform developed at the University of Turku, Centre for Learning Analytics. It was first developed as a tool for teaching programming at university level, but it soon expanded to include many different exercise types and other features, like electronic exams (Kaila, 2018). The versatility of automatically assessed exercises with immediate feedback is the unique feature of ViLLE (Laakso, et al. 2018). The main idea is to provide exercise templates to basically any subject, from mathematics and programming, to languages and social studies. Currently, there are more than 150 different exercise types that can be used for exercises in various subjects. Learning paths are provided, for example, for Finnish language, introductory English and programming, in addition to the learning path for mathematics. This thesis concentrates on the digital learning path for mathematics and uses the abbreviation DLP to address it. However, all the other learning paths have followed similar design and creation process collaboration with teachers.

ViLLE is not only a technical tool, but also incorporates best practices in how to integrate TEL in teaching or learning. The idea has been, since the beginning, to build a tool together with educators to ensure the suitability of the tool in real life. Kaila (2018) describes in his thesis how the structure and practices in university level programming courses were changed to support learning and improve the learning performance of students. The technical and non-technical principles of the DLP are presented in more detail in the next chapter.

3.2 Design principles of the Digital Learning Path

A digital learning path is a set of digital exercises that integrate into normal curriculum and classroom activities, and provide learning analytics for the teacher. Our recommendation and guideline in research setups is that learning path exercises are used once a week in school (P1, P2, P3, P4, P6).

The DLP was designed and created in tight collaboration with teachers and the effectiveness of the design has been evaluated in numerous studies (e.g. P1, P2, P3, P4, P6). In this way, best practices that work in classroom setting were found and integration of TEL became smoother. We wanted to create a TEL solution that could be utilised regularly and would bring measurable and scientifically solid benefits to students and teachers. The requirement for regular usage arises from the NCTM (2011) statement and many studies (eg. Slavin, et al. 2008). If teachers are to get onboard, they need to continuously use the platform in order to realize clear benefits.

We had three equally important goals in mind when we started to design the DLP. First, we wanted to improve students' motivation and learning performance. Second, we wanted to make the usage of the content as effortless as possible for the teacher. Third, we wanted to provide more learning data for the teacher. Since then, these goals have proven to be diverse and have many new nuances. In this thesis, I am not trying to find out which of the design principles is the most important or most effective, rather I want to introduce the ideas on which the DLP has been built.

Finland is known for its reputable education system. It was clear from the beginning that too big changes could be challenging and we would not want to make any drastic changes to existing workflows. Based on previous experiences and results from university level students, substituting parts of traditional teaching with TEL was the best choice. Keeping changes small and manageable for the teachers and students was prioritized, to increase the likelihood that successful change could occur. Studies show adaptation can be cumbersome, but results can improve with a 30-75 minutes exposure per week (Slavin, et al. 2008; Cheung, et al. 2013). Typical Finnish school lessons are 45 minutes. In primary education students have 3-4 mathematics lessons per week. It seemed plausible that substituting one mathematics lesson each week with TEL should provide noticeable improvement to students learning performance, and it would give each student an equal opportunity to use TEL at least in school despite the availability of equipment at home. Learning and practicing mathematics with exercise books is based on repetition and drilling. Most of the problems presented in a primary level mathematics exercise book can be assessed automatically or adapted in a way that allows automatic assessment. Our idea was to take the time for TEL from that pen and paper work and partly substitute it with technology, but only when technology made sense. This would also build a base for regular TEL use instead of it being something that was used to fill spare time.

3.2.1 Creating together

All the content in the DLP was co-created with teachers and developers. In this case, the developer was a researcher with teacher proficiency. First the developer was me and later on me or my colleague. We used the cycle and steps introduced in Figure 3 to ensure that suitable level and type of exercises were used in each lesson.

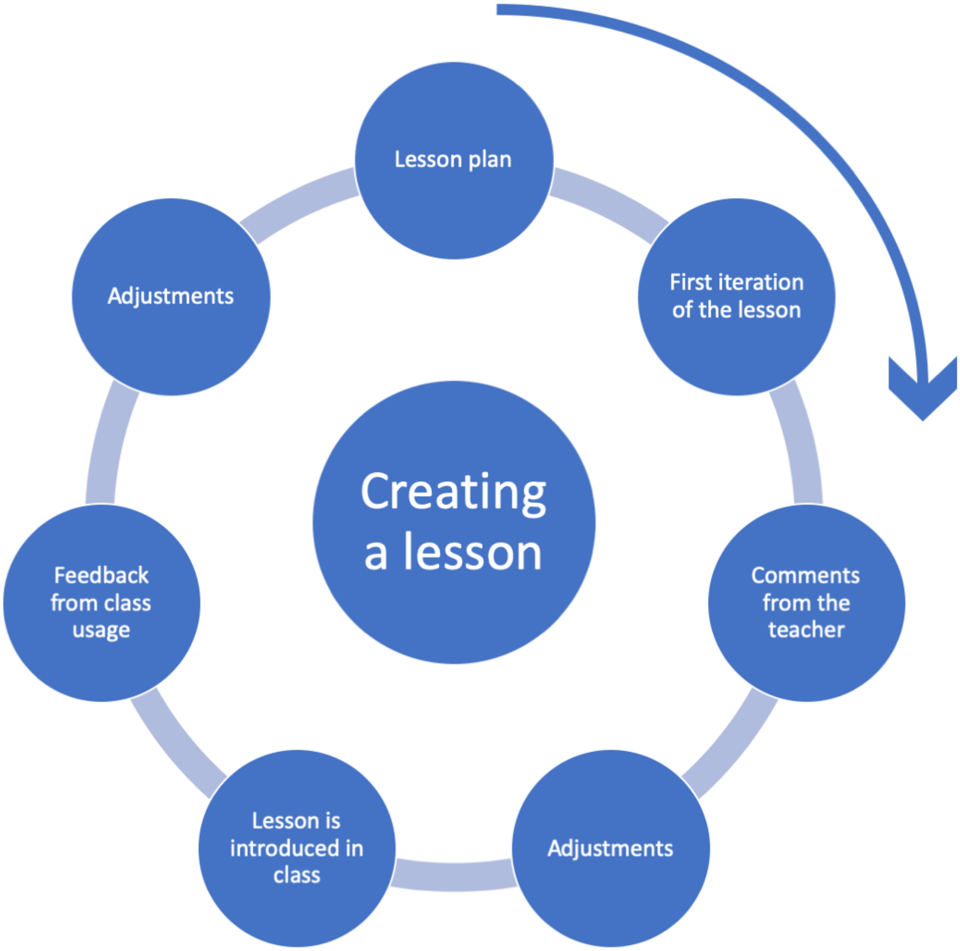

Figure 3: Co-creation cycle for creating the lessons in the digital learning path.

First, the DLP lesson plan is prepared by the teacher and developer. The lesson plan contains topics that the teacher will introduce to the students during that week. Hence, it's not just one topic per lesson but possibly a combination of several topics related to each other. Based on this plan, the first version of the lesson is created. This means creating the exercises. The developer completes this step. After creating the first version, the teacher tests the lesson and provides feedback. Based on this feedback, the developer makes further adjustments to the lesson. The lesson is then ready to be introduced to students. Teachers and students work on the exercises and the developer receives feedback from the students and the teacher. In many cases the developer was able to join the lesson and observe. Classroom feedback gives valuable information on the small nuances going on in the classroom. This feedback helped us to find best practices and helped to make adjustments to the lessons as well as learn which aspects we are still lacking.

After completing all lessons for one grade, the lessons are compiled into a course and made available in ViLLE (Table 2). Teachers and students were still able to give continuous feedback on the content and individual exercises from the platform. Teachers also could participate in surveys, as was used in P5, to give more feedback. The design principles which formed as the foundation of DLP emerged due to this process.

The DLP currently covers the entire curriculum for grades 1-9. Grades 10-12 (upper secondary school) are in the making. Table 2 describes the number of exercises and lessons and thus demonstrates the versatility of the content.

Table 2: Composition of lessons in the different grades in digital learning path

Age group	**Grade**	**Lessons**	**Exercises**	**Average exercises per lesson**
7-8	1	40	1692	42
8-9	2	48	2209	46
9-10	3	48	2053	43
10-11	4	43	1948	45
11-12	5	41	1842	45
12-13	6	43	1951	45
13-14	7	81	2283	28
14-15	8	80	2238	28
15-16	9	52	1449	28
Total		**476**	**17665**	

The lower number of exercises in grade 7, 8 and 9 (Table 2) can be explained with the lack of differentiating preliminary exercise sets. Currently, this is work in progress. Also, the number of lessons is higher. Each grade, 7-9, contains overlapping lessons due different mathematical structures in various courses in different schools.

3.2.2 Lessons

Traditional mathematics teaching with exercise books is typically well structured and often teacher led. Most students work on the same exercises in the same sequence. There might be students with differentiated exercises who work on books with easier tasks, but even that is controlled by the teacher.

There have been Intelligent Tutoring Systems (ITS) with adaptive content since the early 1970's (Nwana, 1990). However, there does not seem to be a platform that is being used and widely accepted in primary mathematics education. The theoretical question becomes one of why there is the huge gap between traditional teaching and ITS. That being said, to support learning to read Ekapeli, or Graphogame has been widely used in Finnish schools and that includes adaptive content, but is for a very specific domain (Richardson & Lyytinen, 2014). We wanted to make our DLP as transparent as possible for teachers but still be able to provide the advanced differentiation tools and other benefits that TEL provides.

For the purpose of one TEL lesson in a week, we designed lessons in DLP for every school week. Each lesson would cover roughly the topics practised in one week. We also made the decision of including some revision exercises to practise previously introduced topics, to keep them in the minds of students. Based on teachers' experiences, topics that are easily forgotten included, for example, multiplications, columnar addition and subtraction, fractions and unit conversions. All the lessons have been created in close collaboration with teachers and their classes. The content is still constantly updated based on feedback from teachers and students. All updates are automatically propagated to teachers.

The lessons are built mostly for practicing and rehearsing topics that have been taught by the teacher. However, they can be used to introduce new topics, especially if the work is collaborative. Collaborative work enables students to solve and discuss the problems together, which might help them solve even new problems (Moss & Beatty, 2006; Rajala, et al. 2015; Chaiklin, 2003; Vygotsky, 1978).

There are numerous pedagogical ways to approach mathematical problems, which is why we decided to have as little instructional parts as possible to keep the material flexible and allow the teacher to be in charge of the pedagogy. Each lesson contains around 20-30 exercises that are visible for students by default. In addition, there are 10-15 hidden exercises that can be made visible by the teachers, if they feel necessary. Students do not need to complete all the exercises to complete a lesson. They collect trophies, which are achieved by reaching 50%, 75%, 90% or 100% of the scores (Figure 4). The trophies are explained in more detail in the chapter on gamification. Table 2 lists all grades, the number of lessons and the number of exercises in them on average. The default set of exercises should be more than suitable for general purposes. However, we included the opportunity for teachers to customize the material. Teachers can hide or show exercises as they wish. More exercises can be added from other lessons, or even complete lessons can be brought to the current grade from other grades.

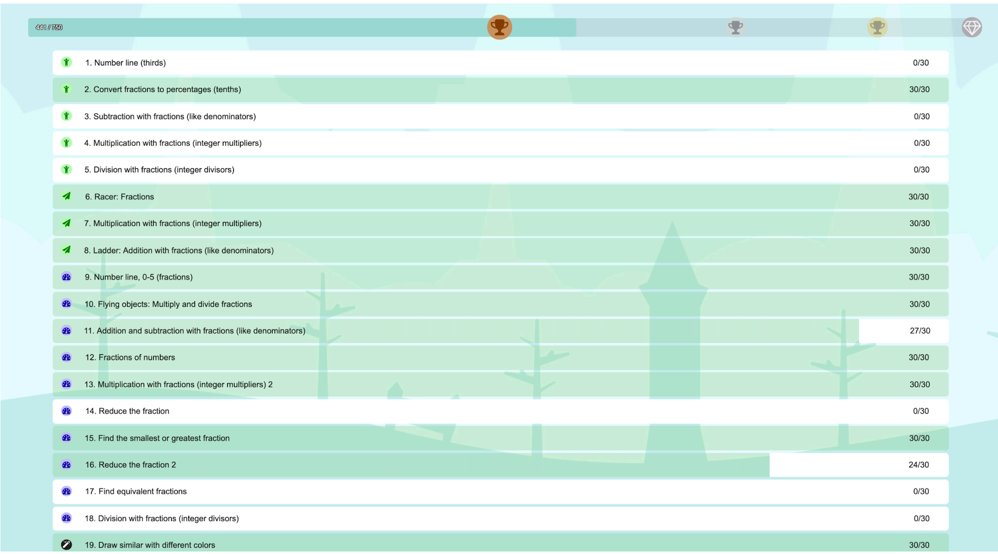

Figure 4: Example lesson "Revision of fractions and mixed numbers". The trophies and thus the process can be seen at the top of the image. Each exercise is also presented as a progress bar to put emphasis on the current progress.

As seen in Figure 4, the student has already achieved the minimum requirement for bronze trophy. He/she has not completed the exercises in order. In addition to lesson progress on top of the image, each exercise is also a progress bar indicating how many points the student scored from the exercise. The best result for each exercise is kept, and students can try any of the exercises as many times as they like. Once the student achieves 30 points (the maximum from one exercise), there will not be any additional points to lesson progress, hence they need to move to the next exercise.

Our goal was to approach the mathematical problems from a wide angle when compiling the lessons. Concrete examples and visualisations support students in early phases, repetition and rote learning help building routine, but we also wanted to promote different strategies to solve problems and present problems in various ways. In spoken language, rote learning is usually a synonym for memorisation. In a mathematical context, rote learning refers to passive storage view of basic arithmetic facts. Our point of view was more on the side of number sense view, which promotes understanding. (Baroody & Rosu 2006.) Our approach was to promote different strategies instead of memorization using various exercise types.

In the 1950's, Bloom (1956) introduced a six-level taxonomy to describe reasoning skills that can be observed in classroom situations. There are multiple revisions and extensions to the famous Bloom's taxonomy which try to clarify the meaning of each step. Nowadays the most widely used version of Bloom's Taxonomy is the cognitive process dimension. (Krathwohl, 2002.) The levels are typically presented in a form of a triangle (Figure 5). The skills need to be gained in steps from bottom to top. Students can't skip steps.

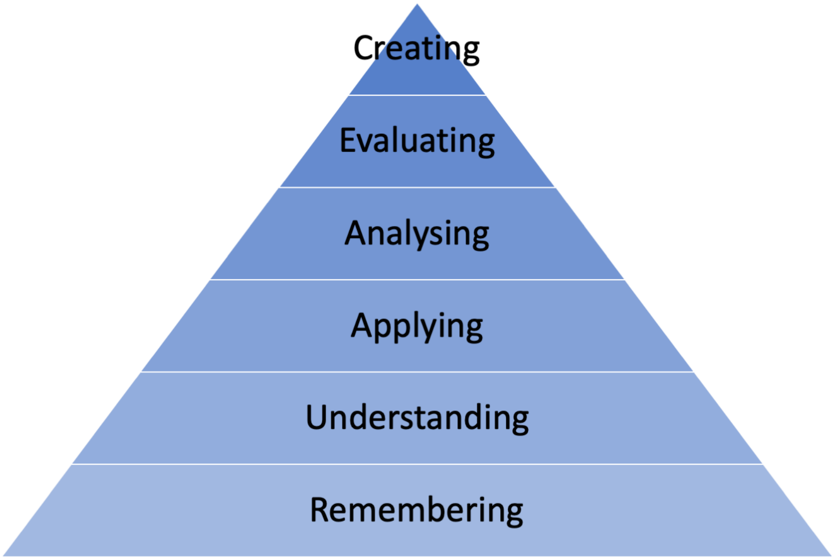

Figure 5: Bloom's taxonomy, cognitive process dimension.

TEL is really good at the first level, remembering. Computers (in a broad sense) are tireless trainers that keep asking questions and keep giving calm and objective feedback. In addition to being tireless, TEL also enables making practicing this step more engaging and motivating compared to pen and paper methods. I consider this level being the "rote learning" level. The second level, understanding, is the next step from rote learning. This covers for example arranging numbers to ascending or descending order or placing values on a number line. The third level, applying, is probably presented the best by word problems. In word problems students need to apply the understanding of arithmetic operations in order to solve the problem. The fourth step, analysing, is more demanding. Some simulations we used required analysing the situation and drawing conclusions. Step five, evaluating, is achieved by implementing pair-work capabilities of ViLLE. Two students can work together on one computer on the exercises and solve the problems. However, in my opinion, step five, or even step four and above are difficult to fulfill purely with TEL because they require social collaboration. This does not however mean that TEL or ViLLE could not be the facilitator for these actions. It is more about the execution in classroom rather than exercise design.

3.2.3 Active learning

Active learning is basically any instructional method that engages students in the learning process. It requires meaningful tasks or learning activities and students to think about what they are doing. Typically, active learning refers to in-class activities opposed to homework, for example (Prince, 2004). In contrast to active learning, lecture-like teacher-led teaching is often referred as passive learning. Active learning is sort of an umbrella term to describe many of the key features in DLP. Our goal is to increase active learning time in class, and many of the means to increase active learning are discussed in more detail later.

Randomisation of questions is one way of promoting active learning. In cases, where students make a lot of mistakes, this makes practising sensible. Instead of repeating the same questions and slowly memorising the answers, there are always new problems to be solved. Another advantage of randomisation is the fact that students sitting close to each other can't just copy the answers, every problem actually needs to be solved by the student.

If teachers follow our recommendations of using the DLP for one lesson a week, students solve, on average, 150-300 calculations in each DLP session. In an exercise book, there might be as few as 20 calculations for a lesson. A good estimation could be somewhere around 50 or 60. The actual number is really hard to estimate because it depends on the book series used and the topics covered. The numbers presented here are a rough estimate. Assuming that an exercise book covers 20-60 exercises, it would mean that students solve, on average, somewhere between 3-8 times more calculations in the DLP lesson than in a normal lesson.

Another way to help active learning is by supplying all homework in ViLLE. This way, the teacher has constant view into students' answers. They can see who have completed their homework, which exercises were easy and which exercises might need revision. All this can be prepared before the lesson. In a typical case, the homework is checked together in the beginning of the lesson, no matter if students mastered them or not. By saving this time, we give more time for learning in class.

Collaboration is one form of active learning (Prince, 2004). One feature of ViLLE is the ability to pair students. Two students can use one device and solve the problems collaboratively. Both students will get the points and can continue individually later, if they wish (Rajala, et al. 2015). Even without this feature, ViLLE lessons tend to be quite social. Students are eager to help each other and are interested in each other's advancements. This observation is based on my own experience in hundreds, if not, thousands of class visits, conversations with teachers and feedback from teachers.

3.2.4 Automatic assessment

Probably, the greatest time saving for teachers comes from automatic assessment (Laakso, 2010). Traditionally, teachers need to assess all school work of students, exercise books, worksheets and tests. Assessing is a window for teachers to see how students are doing. Assessment is also a window for students to obtain feedback about their work. Concerning worksheets or exercise books, students might have occasional access to answer sheets to check their answers and do the assessing without the help of the teacher. In traditional teaching, assessing tends to concentrate in tests and exams, and is not conducted continuously. This is understandable because it would take a lot of time and effort to do all assessment manually. Teachers need to optimise their scarce time. Automatic assessment is also a prerequisite for immediate feedback and continuous assessment in addition of being one of the main benefits for teachers.

In primary mathematics (and why not languages as well) many tasks are easily assessed automatically. Typically, there are not many steps or the answers are unambiguous. It is also possible to change the structure of an exercise to make it automatically assessed. Usually, the easiest way to change an exercise is to change the exercise to multiple-choice question or classification exercise. The correct answers can be predefined, or students' answers could be evaluated against certain rules. For advanced mathematics assessments, we use symbolic calculator to evaluate the input given by students. If an answer is based on a string comparison, we try to avoid common pitfalls by ignoring whitespaces and capitalised letters, if not explicitly defined otherwise.

3.2.5 Immediate feedback

TEL enables students to get personalized and immediate feedback that supports their learning. Immediate feedback can be seen as an integral part of scaffolding and Vygotsky's idea of Zone of Proximal Development (ZPD) (Sharma & Hannafin, 2007). ZPD is discussed in more detail in the differentiation chapter. Scaffolding is defined as interaction between an expert (teacher) and a novice (learner), (e.g. Pea, 2004). In context of TEL, technology can substitute the expert as a human, and provide some scaffolding for the learner. Scaffolding, in the context of TEL, can be divided into: routine scaffolding and dynamic scaffolding (Sharma, et al. 2007). Routine scaffolding is simple and straightforward feedback from learners' actions, for example, information, if the given answer was correct or incorrect. Even this kind of routine scaffolding can help students work individually without the need for teacher's intervention. When most of the students can make progress on their own, teacher's time is freed to help students with special needs. See Figure 6 and 7 as examples of the feedback that ViLLE gives to students. The feedback given by ViLLE falls mainly under routine scaffolding. Dynamic scaffolding refers to feedback that has traits of human given feedback. Implementing dynamic scaffolding is more time consuming and thus more expensive to create. In addition the same feedback might not be reusable over different exercises. (Sharma, et al. 2007).

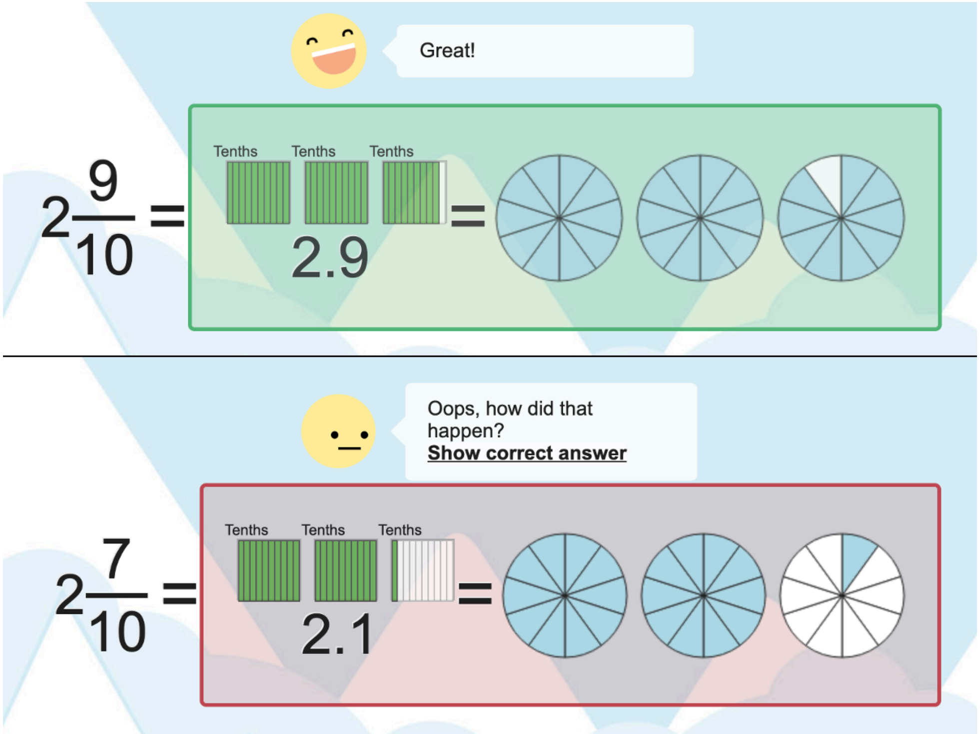

Figure 6: Convert fractions to decimals. Correct and incorrect answer by student.

In Figure 6 the example above is from a correct answer given by a student. It also shows the different notations and visualisations for the given number. In the incorrect feedback the answer given by the student is not equal to the correct answer. The student is able to view the correct answer by clicking "Show correct answer" and thus compare the given answer to the correct answer. The example feedback in Figure 7 shows an example of a more advanced feedback that guides the student towards the correct solution.

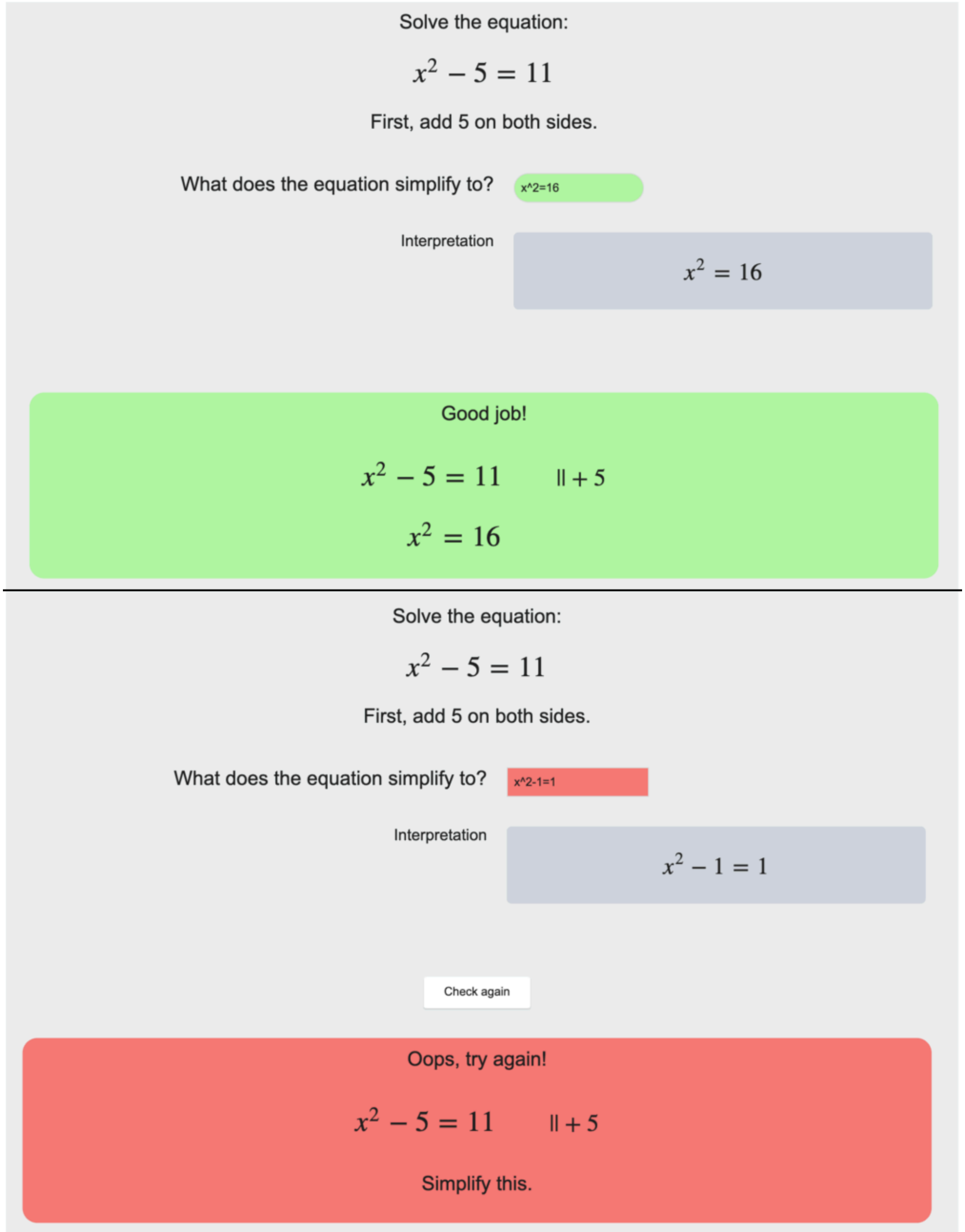

Figure 7: Example feedback from solving equation in steps. Correct and incorrect answer.

The advantage of personalised and immediate feedback is speed of the feedback loop, which can be beneficial for learning and learning performance (Brosvic, Dihoff, Epstein & Cook, 2006; Harskamp, 20014; Hattie & Timperley, 2007). No matter how effective the teacher is, there is no way they can provide as much feedback as TEL solutions. Immediate feedback is important for student engagement but it can also improve students' self-confidence (Attard & Curry, 2012). That being said, the feedback given by a teacher is still highly valuable, while humans are really good at dynamic scaffolding.

Taking the full advantage of given feedback is up to the student. Some students use brute force methods to get correct answers, but this strategy is time consuming and yields low results. There are multiple mechanisms in place to make sure students are not rewarded trial-and-error strategies in the DLP.

3.2.6 Heterogeneous Exercise Types

Prensky (2001) lists twelve elements of what makes games so addictive and engaging. Among others, he lists: rules, interactivity, goals, feedback, win state, challenge, problem solving, interaction and adaptivity/flow. Many of these aspects are present even in the pen and paper like exercise types.

There are currently over 150 different exercise types in ViLLE. Variable exercise types bring versatility and engagement when combined with automatic assessment and immediate feedback. Some exercise types are game-like, and they contain familiar elements from entertainment games, like time limits, lives and cartoon-like graphics. (Figure 8). The game mechanics are kept as simple as possible to help reduce cognitive load associated with the game elements. By having simple graphics and gameplay, we want to promote the learning aspect of the games. Better graphics do not mean better learning outcomes, as long as the graphics are "good enough" (Vogel, et al. 2006; Kao & Harrell, 2017). Better graphics have been linked to higher engagement, but it did not yield better learning performance (Kao, et al. 2017). Rodríguez-Aflecht, et al. (2017) concluded, that games alone won't improve students' motivation. Serious games should not be used just for the assumed increase in motivation but for their learning content.

Figure 8: Same content presented in different exercises. All of them are essentially multiple-choice questions.

In addition to games, there are many exercise types that resemble traditional pen and paper exercises (Figure 9). All the exercises give feedback and are randomised, if possible. Some exercises have dynamic visualization, either in the actual task or in feedback (See Figure 6 & 7). The games with multiple sub-tasks are also adaptive and they will repeat questions that the user answered incorrectly at some point. This is not necessarily right after the incorrect answer.

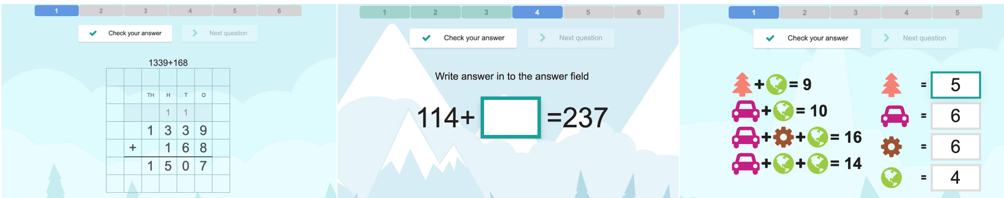

Figure 9: Examples of more traditional exercise types. From left to right: Columnar addition, fill-in the missing attended and simultaneous equations.

By offering variety in exercise types and exercises, we want to provide versatility to students. Students do not need to complete all exercises in order to complete a lesson, hence they can prioritise the exercises they prefer. This also gives them the somewhat rare opportunity for autonomy. The order of exercises or number of exercises to complete is not fixed as long as the student completes the minimum goal set by the teacher (50% by default). This gives students the freedom to choose suitable exercises for their skill level or mood, and thus, keep up the flow.

3.2.7 Gamification

Gamification combines elements from games into other activities, like learning (Deterding, 2011). Gamification does not require technology, but technology can provide assistance and automation of score keeping, or keeping tabs on each student's progress. The goal of gamification is to make learning more attractive and increase the motivation of students (Lee & Hammer, 2011). If technology is not used for gamification, many aspects of it becomes dependent on the teacher, and there is a delay between students' efforts and seeing the results. In the case of ViLLE, we use technical solutions but also recommendations and best practices to be used outside the platform (e.g. Figure 10). Our guidelines for gamification follow the guidelines used by Simões, Redondo & Vilas (2013). The guidelines and their practical implementations are described in Table 3.

Table 3: The gamification guidelines and their corresponding implementations in ViLLE.

Guideline	**Implementation**
Allow repeated experimentation	The number of trials on each exercise is not limited. The best score achieved is the one that counts, hence it is safe to try the same exercise again. Randomisation of questions make experimentation more meaningful.
Include rapid feedback cycles	Immediate feedback is an integral part of all exercise types. Students will get feedback from each exercise but also from sub-tasks, when possible.
Adapt tasks to skill levels	Exercises in one lesson range from basic level to advanced and problem solving. The minimum goal to achieve is bronze (50%), which does not require completing all tasks. Students can choose themselves. Many exercises include three difficulty levels: easy, moderate and hard. Students can also choose from these freely. The chosen option does not affect scoring but it is made visible for teacher in the statistics. See the chapter on differentiation for more information.
Increase tasks' difficulty as students' skills improve	Exercises in lesson get more difficult by lesson design. Also, there are many measures in place to ensure suitable difficulty level. See more above and in differentiation chapter.

Guideline	Implementation
Break complex tasks into shorter and simple sub-tasks	The exercises and lessons are by nature divided into simple sub-tasks. The length of one exercise is kept short to moderate to give the students clear feeling of advancing.
Allow different routes to success	There is a lot of freedom for students to choose from. This is not the case in traditional lessons. By giving students the possibility to choose, we hope to get students to be more responsible for their learning and improve their metacognition.
Allow the recognition and reward by teachers, parents and other students	This is one of the most important points, and most of this happens outside the platform. We encourage teachers to have for example a "scoreboard" visible in the classroom for example (Figure 10). The older the students get, the more important it is to tie the hard work to assessment. We have seen multiple strategies to give recognition to students. For example, if the students gain enough trophies, they might get extra points for a test. Another popular way to give recognition and share progress with parents is giving a positive note on a digital communication tool being used between the school and parents. It is equally important to note if the students have not completed the lesson in the given time frame. This sends the message that the work is not insignificant.

At the end of the day, working on digital exercises is not that different from completing tasks in an exercise book. The goal is to integrate ViLLE as part of mathematics education, as much as exercise books nowadays. In order to achieve this, the teacher must have a clear framework describing how to implement ViLLE as a weekly activity. This includes how often and when ViLLE should be used, and what is the goal for students. There also needs to be similar consequences for not meeting the goals, as in other school work. Our recommendation is one lesson (45 minutes) a week and homework, and one lesson (topic) in ViLLE. Positive reward and recognition should not be forgotten due its power to increase motivation.

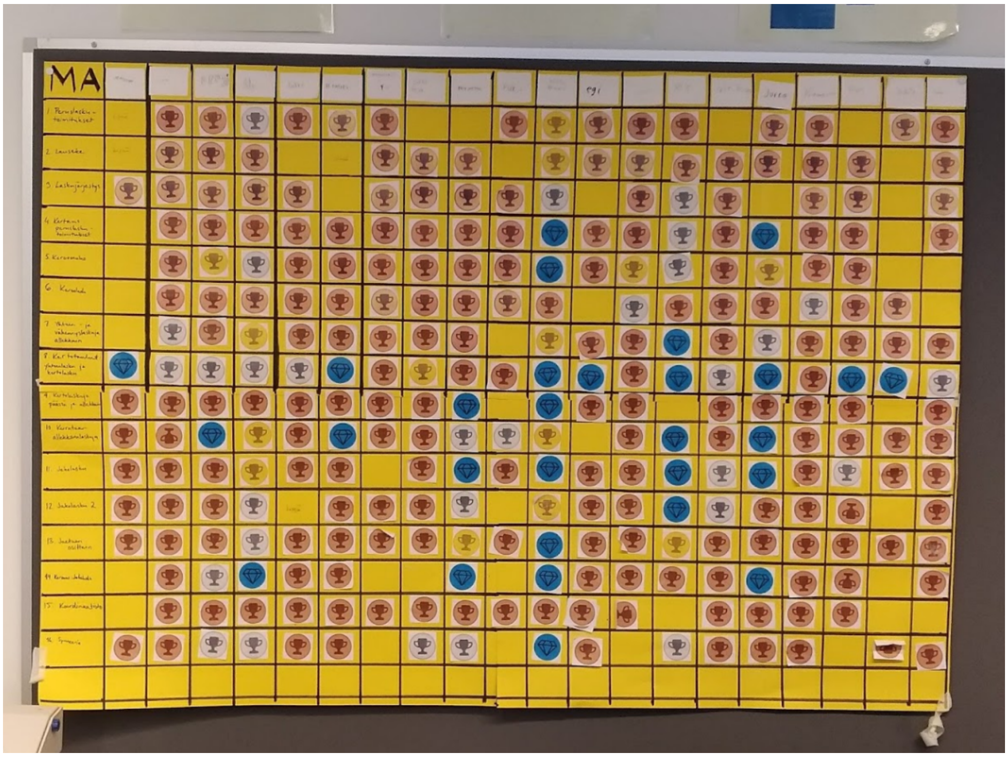

Figure 10: Scoreboard of trophies from each lesson.

There are different ways to implement scoreboards in class. The scoreboard in Figure 10 shows the progress of individual students. Sometimes, personal advancements might be discouraging and a common progress would be more motivating. In another template, teachers could write down the weekly count for bronze, silver, gold and diamond trophies. Every student will see their own progress through ViLLE in the student dashboard (Figure 11).

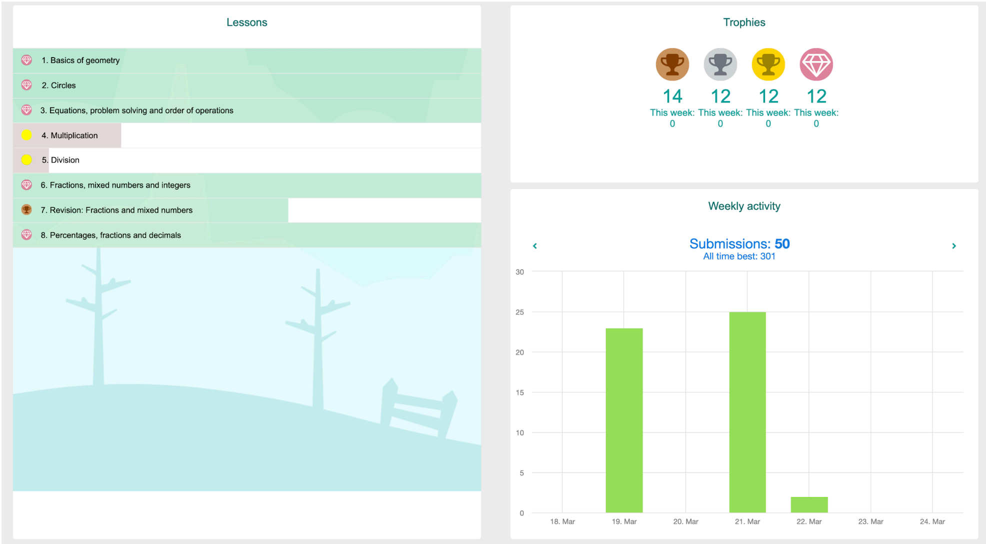

Figure 11: Student dashboard shows lessons opened by the teacher, current trophy count for all lessons and activity during current week.

In the student dashboard (front page, Figure 11) students see the lessons that have been made visible by the teacher. Experience has shown that it is a good idea to open one lesson a week to give a clear goal for students and not to overwhelm them with too many tasks. Each lesson in the dashboard is a progress bar, and the achieved trophy can be seen before the lesson's name. In addition, students will see their total trophy count in "trophies". Last, students can see their daily activity divided in weeks. The chart shows the number of exercise submissions on each day.

3.2.8 Differentiation

Vygotsky's Zone of Proximal Development (ZPD) is one of the most recognised theories from Vygotsky. The core idea of ZPD is that with the help and support from an adult a child is able to accomplish tasks that would otherwise be too difficult. By time, the child will learn to accomplish supported tasks on their own, hence the whole process is very dynamic (Chaiklin, 2003; Vygotsky, 1978). Scaffolding was mentioned earlier as a concept, where expert supports the work of a novice. In scope of this thesis, the expert is TEL, which gives feedback to student (novice). How does ZPD differ from this and how does it relate to differentiation? The key is the “zone”. First, we need to find out in which zone the student can work without help. After this, we can “stretch” this area further with help of scaffolding. Each child has a different zone and “stretch” of how far this area goes with scaffolding, which is why we need differentiation. The zone is not static either but it changes over time. If the task provided is too easy, it causes boredom and it will not advance learning as much as possible. On the other hand, too difficult tasks will cause frustration and also prohibit learning. With differentiation the goal is try to find the middle ground which allows the learner to study with just the right amount of challenge.

Traditionally differentiation is a tedious and time-consuming task. TEL helps to make differentiation easier. There are multiple ways to differentiate students in ViLLE either as a class, smaller groups or individuals. Teacher is mainly the one who makes the differentiation choices to keep the transparency. The only exception to this is built in difficulty levels in some exercises, where students can make the choice on their own. Even in these cases, the choice is saved and shown to teacher in the statistics. Below are listed the different possible approaches the DLP enables for differentiation.

Reduce workload

By default, there are about 20-30 exercises visible for students in each lesson. By reducing the number of lessons visible, you will automatically reduce the demanded workload for achieving the bronze trophy. The difference between adjusting trophy levels and reducing the number of exercises is the freedom of choice. With reduced exercises, there are less options to choose from, and it will force students to make similar decisions.

Trophy levels for all

Sometimes it is necessary to adjust the workload of the lesson for the whole class. This can be achieved by adjusting the trophy levels for all. For example, by default the bronze trophy is 50%. In other words, students need to complete half of the visible exercises. By reducing this to 30%, also the number of required exercises completed is decreased, and there is a larger pool of exercises to choose from.

Individual trophy levels

Depending on the skill level of the class, it is possible to customize the goals of the lesson for the whole class or individual students by adjusting percentages of the trophies. This is especially efficient for students who have no problems in academic skills but are just slow or have low motivation. When they achieve the first trophy easier, it might help them to reach out to the next trophies easier.

Preliminary assignments and bonus assignments

Adjusting workload is not enough, when students are clearly struggling on the current topic. In this case, we are clearly out of the correct zone. For these cases, we have prepared preliminary assignments to ease students' path to normal exercises. Preliminary exercises are mostly related to the current lesson's topics, but from earlier grades or practice fundamental skills, like numberline and basic arithmetic facts.

Teacher can enable bonus assignments for students who get frustrated with the basic exercises. Preliminary and bonus assignments broaden students' options to choose from exercises. They don't change the maximum score of the lesson, which means that students can achieve the diamond trophy (100%) without completing all visible exercises. Without differentiation in the material presented to the student, the diamond trophy requires completing all exercises correctly. This is especially important for low-achieving students' self-confidence and empowerment. From the teacher's perspective, this just encourages students to work harder and improve their skills, and the teacher still knows which students are working with additional and supplementary material and which are not.

Different grade level

When even preliminary or bonus assignments are not enough, the teacher should consider letting students work on exercises from different grade level. Especially special education teachers typically select courses that are clearly on a lower level than the student would otherwise be. The grade level is mentioned only in the course's name, which can be changed by the teacher.

3.2.9 Learning analytics

In addition to automatic assessment, the most important feature of TEL for teachers is the learning analytics (LA). The Society for Learning Analytics Research (SoLAR) has defined Learning analytics in Conference on Learning Analytics and Knowledge (LAK 2011) in the following way: "Learning analytics is the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimising learning and the environments in which it occurs". In other words, LA helps teachers notice and react to individual students' strengths and weaknesses.

When students work in ViLLE regularly, the teacher has live data on students learning progress, hence learning analytics makes continuous assessment effortless. The knowledge gained from learning analytics can be used to adjust instruction outside TEL as well, or it can be used to make decisions on differentiation on the platform. When data is collected by a TEL solution, the teacher does not need to process the data separately, like collecting exercise books and going through each question. With the help of TEL, LA becomes the eyes and ears of the teacher even in large classes. Everyone has the equal attention of the TEL solution. LA becomes really powerful when teachers can combine their knowledge of individual students with LA system (Kanth, et la. 2018).

The most used statistics and analytics have been made readily available to the teacher. These include student diligence (Figure 12), lesson progress (Figure 13) and misconceptions (Figure 14). In addition to these summative statistics, teachers can go into details all the way down to questions level. However, for daily usage, the summative reports are usually more than enough.

Figure 12: Teacher dashboard and with trophy counts, weekly activity, lessons and student diligence.

When a teacher logs in, he/she is presented with a dashboard (Figure 12) that summarises the current courses' (grade's) progress. On top left are all the trophies achieved by students and new trophies from the current week. Below the trophies are the lessons. Blue-eyed lessons are visible to students, and each lesson is a progress bar that shows how many points students have collected collectively. On the right is the weekly activity, which shows how many exercise submissions students have made on each day during the current week. The best week is shown for comparison. The most elaborate analytics in this view is the student diligence: it visualizes each student as a dot, horizontal axis shows achieved scores, and vertical axis shows time usage. The further right the students' dots are, the more points they have gained. The lower the dot, the faster the scores have been achieved. High achieving students are on the bottom-right corner of the chart. These students might benefit from more difficult exercises. When a student is struggling, the time usage typically increases. These students are clearly visible for rising more towards the top side of the chart. Last, inactive students are easy to find from the left side of the chart.

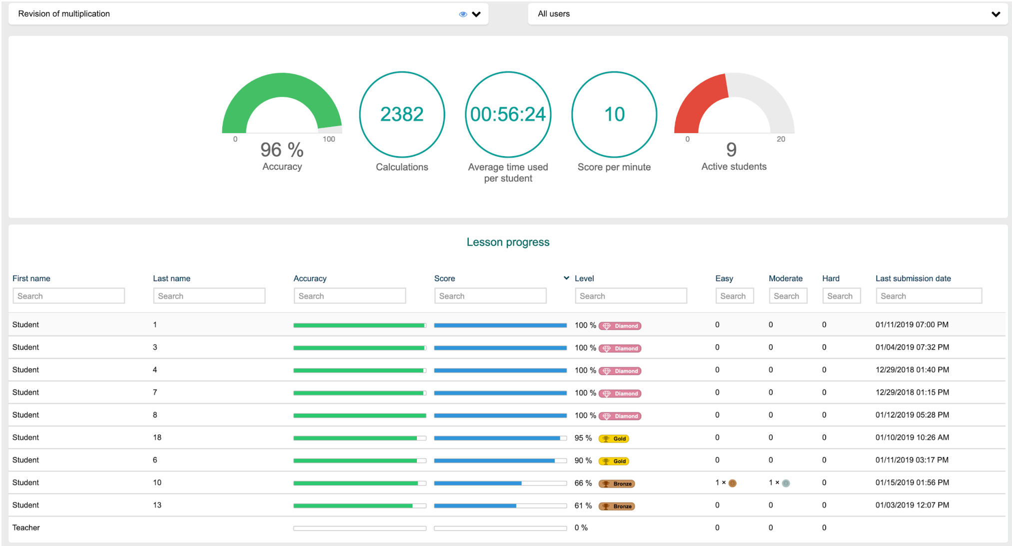

Figure 13: Progress for one lesson. This statistics is used to observe each students' progress in a selected lesson.

Lesson progress (Figure 13) is the default view in statistics. It shows the last lesson with student submissions. First, there are key statistics, the most important include the average accuracy of students and the number of active students in the current lesson. Below, these numbers are individual lesson progress bars for all students in ascending order by scores achieved. From this table, teachers can easily see which students have achieved trophies but also teachers can see their accuracy (ratio of correct and incorrect answers over all submissions). When accuracy drops, the bar changes to orange and red to highlight problems. Easy, moderate and hard columns show which difficulty level the students have chosen, if the option was presented.

Misconceptions

Name	Long calculation	Perception	Multiplication	Calculation in a row	Addition	Subtraction	Equality
Student 11	5	*	5	*	5	5	5
Student 18	4	*	5	*	5	4	5
Student 9	5	*	5		5	2	5
Student 6	5	*	5	*	5	5	5
Student 5	5	*	4	*	4	1	5
Student 17	5	*	2		5	5	5
Student 14	4	*	3		5	4	3
Student19	5	*	5		5	5	5
Student 1	5	1	5	*	5	5	5
Student 4	5	*	5	*	5	5	5
Student 10	4	*	5	*	5	3	5

Figure 14: Automatic recognition of misconceptions. The analysis works in a traffic-light manner. Green indicates good skills, orange indicates average skills and red indicates problems.

Automatic recognition of mathematic misconceptions can be visualized as a lesson proceeds (Figure 14). The table lists all subtopics in mathematics exercises and shows how well students master each. The analysis works in a traffic light manner, green indicating good skills, orange indicating some problems, and red indicating many problems and possibly need for teacher intervention. This analysis was studied in Lokkila, et al. (2015) and compared against the widely used MAKEKO test in Finnish schools. A strong correlation was found between the automatic recognition of misconceptions and the MAKEKO test. The analysis can be used to find students with multiple difficulties or a teacher can see if there are difficulties in one or more topics for the majority of the class.

4 Evaluating the Digital Learning Path in Mathematics Education

This chapter begins by detailing the creation and rationale for tests in mathematics performance and arithmetic fluency. Next, the path for building the DLP on top of ViLLE is described. Finally, steps and reflections on previous research papers included in this thesis are explained. A synthesis, including the effect size for each research reported, is presented. Finally, this chapter concludes with teacher perceptions reported in P5 and what we have learned from them.

4.1 Mathematical performance

In Finland, national tests begin for students in 9th grade. Even then, the tests are conducted only on a sample of the student population. The test results help provide a clear picture of the current state of education in Finland. The test is not really not a national test in the traditional sense, because it is not meant to assess individual students but to inform policy makers. The only actual national test for all students is the matriculation examination but that only concerns students who attended the upper secondary school (grades 10-12). We needed a test to measure and compare changes in students' mathematics performance. All tests, including arithmetic fluency test, have been conducted in pen and paper format to avoid favoring the group using TEL.

When we started to design the test, we first studied the national mathematics curriculum for the target grade (POPS, 2004). Unfortunately, the curriculum is not very exact and it leaves room for interpretation. To fill in the blanks, we used widely accepted tests such as Ikäheimo's "KYMPPI-test" (Ikäheimo, 2012) and various other studies recommended by Niilomäki Instituutti (Koponen & Aunio, 2008). The purpose of the tests was to collect key topics students should learn during each grade. We reduced the risk of testing something that was only taught for one of the classes by matching the content used in ViLLE to content in mathematics books, and ensuring both the control group and treatment group used the same books. A third group of students of similar age were used to assess the understandability, difficulty level and the length of the test.

4.2 Arithmetic fluency

By arithmetic fluency we mean how rapidly and accurately students solve three exercises involving basic arithmetic operations (addition, subtraction, multiplication), excluding division. Baroody, et al. (2006) uses the term "basic combinations" to describe these exercises. By these, we mean arithmetic operations using digit numbers. For example, 3 + 5 or 9 + 9. The mastery of basic arithmetic combinations is promoted in mathematics education (Baroody, et al. 2006). Good arithmetic fluency has shown to help flexible strategies to solve problems but also, they shown to help students' understanding in more advanced topics (eg. Varol, et al. 2007; Verschaffel, et al. 2007).

For arithmetic fluency test, we compiled 160 calculations. The set starts with easier calculations of addition and subtraction. After appoximately 50 mathmatical exercises, more complex operations, such as multiplications, were added. Students had 3 minutes to solve as many problems as they could. While testing the study, even all adults were not able to finish the whole test in time. For first graders, we removed all multiplications and for second graders only multiplication tables that were mentioned in the curriculum were included in the test.

In the test, we measured the number of correctly solved problems and the number of mistakes made by students. By comparing these two numbers separately, we observed changes in fluency and accuracy.

4.3 Results revisited

In 2012, we started to wonder whether the same principles that worked well in higher education (eg. Kaila, 2018; Laakso, 2010) would work also in primary education. The first experiments were conducted in one class (N=18) without control group and the impact was measured with a pretest posttest comparison. The improvement of students' skills was statistically significant, and the overall attitude of the students seemed very encouraging (Kurvinen, et al. 2012). After these encouraging results, we started to the build basis for a more comprehensive platform. This included designing and coding of new exercise types and new features to ViLLE.

We wanted to build and design the content and learning experience as close to real users as possible. For this reason, we conducted a 10-week study in a first grade class (P1). The scope of the content was first agreed with the class teacher and then we built the matching content in digital format. The teacher had the opportunity to give feedback from the exercises before the lesson with students, and final feedback was received after the lesson. After each iteration of feedback, all necessary adjustments were made to the content. Before we started the experiment, a pretest was conducted for the treatment class and the neighbor class (control class). The improvement of treatment groups learning performance was, again, statistically significant and, in this case, we had a control group to strengthen our results. We also conducted a survey of the students asking: if students like mathematics, how confident students are over their skills and how useful students think mathematics is. However, based on the variation of answers and small sample size for surveying the students, we were not able to draw any conclusions (P1). From this study, we learned that combining exercises into one set is more motivating for students, instead of having two separated sets of exercises to work on at school and at home. In normal Finnish mathematics books, there are separate exercises for homework.

After these encouraging results, we started the systematic construction of mathematics content for each grade. For this purpose, we found classes in collaboration with a city government, willing to participate in the design and creation of DLP content. While the content was developed in collaboration with teachers, as described in the previous chapter, there was also a study conducted concurrently. Each pilot/treatment class had a control class in the same school. The treatment or control status of the classes was randomly selected. In the study, we conducted pretest, midtest and posttest for all classes. The results are reported in P2 (3rd grade) and P3 (first grade). The preliminary results from the first grades are published in Kurvinen et al. (2015). Note that Figure 2 in Kurvinen et al. (2015) should report the blue line indicating midtest instead of pretest. In addition to mathematics performance measured in all previous cases, P3 also reports results of arithmetic fluency measured during posttest. The results of P3 suggest that the treatment group reached the same level in midtest as the control group in the posttest. This would give the students using TEL a 10 week advantage compared to groups not using TEL. Figure 15 shows how the treatment group's results are pushed towards the high end of test results.

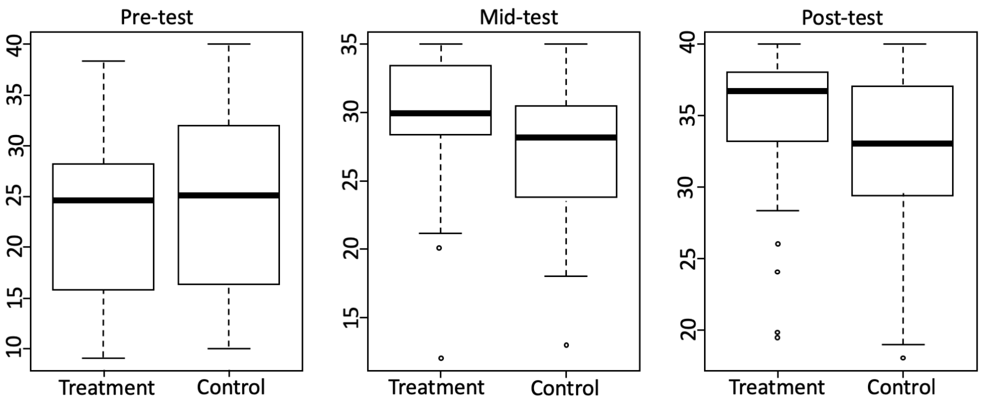

Figure 15: Boxplot visualisation of mathematics performance test results (P3).

Both classes that took part in the research in P1 were willing to continue using ViLLE. At the end of the academic year 2015, we conducted a posttest research that included these two classes along with three other 2nd grade classes from a neighboring school (P4). In this study, we reported statistically significant improvement on learning performance, and a positive, statistically insignificant result on arithmetic fluency. However, the treatment group made statistically significant fewer mistakes in the arithmetic fluency tests compared to the control group.

In 2018, we conducted an international study on the effect of DLP in Lithuania (P6), to see whether the positive results from Finland could be replicated in a different cultural setting. Altogether, three schools and six classes participated in the research (N=140). Each school had two classes, one treatment class and one control class. The content was translated into Lithuanian to eliminate any language barriers. The study lasted 15 weeks and the treatment group showed statistically significant improvement in their learning performance and arithmetic fluency. They also made statistically significant fewer mistakes in arithmetic fluency test, like the students in P4.

Table 4 summarises the findings from all the mathematics performance tests and arithmetic fluency tests. Statistically significant results are marked with X.

Table 4: Summary of research papers and statistically significant results in mathematics performance and in arithmetic fluency. X marks for statistical significance.

Grade	Duration	N	Mathematics Performance	Arithmetic Fluency	Paper
1	10 weeks	40	X	Not measured	P1
3	18 weeks	37	X	Not measured	P2
1	29 weeks	80	X**	X*	P3
2	2 years	82	X**	-	P4
3	15 weeks	140	X**	X	P6

*Arithmetic fluency only in posttest
** Compares the average difference between the groups and the improvement of each student between pre-test and post-test

To conclude, we have achieved statistically significant improvement in all studies in mathematics performance for the treatment group using ViLLE. Proper pretest-posttest arithmetic fluency results were only reported in P6. P6 and P3 show statistically significant improvement in arithmetic fluency, while P4 only showed a positive trend for the treatment group. However, in each of these tests, the treatment group made statistically significantly fewer mistakes. Teacher feedback was positive after each study. Teachers in the control groups reported interest and also wanted to use ViLLE. We realised that starting to use TEL and ViLLE does not happen automatically, but requires well designed training for teachers. This enables us to share best practices and help overcome some of the typical technical and practical barriers teachers face. The traction and training practicalities are presented in more detail in Laakso, et al. (2018).

4.4 Effect size

The meta studies reported in the related studies section used the effect size to measure impact of TEL in student performance. In previous reports, effect size was not analysed or reported. For this thesis, the effect size was analysed.

I followed the formulas proposed by Chauhan (2017) to calculate the effect size for the test. Cohen's d formula (Cohen 1988) was used to calculate the effect size of P4, study without a pretest.

$$d = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{(n_1 - 1)s_1^2 \ + \ (n_2 - 1)s_2^2}{(n_1 + \ n_2 - 2)}}}$$

Where $\overline{x_1}$ and $\overline{x_2}$ are the mean scores from mathematics performance test, n_1 and n_2 are the sample sizes and s_1^2 and s_2^2 are the variance of treatment group and control groups respectively.

For the pretest-posttest setups, a formula suggested by Morris (2008) was used.

$$ES_{\frac{pre}{post}\,Test\ Two\ Groups} = \frac{(\overline{x_{1\,Post}} \ - \ \overline{x_{1\,Pre}}) \ - \ (\overline{x_{2\,Post}} \ - \ \overline{x_{1\,Pre}})}{SD_{post}}$$

Where subscript 1 indicates treatment group and subscript 2 indicates control group. SD_{post} is the pooled standard deviation for the post-test samples.

$$SD_{post} \ = \sqrt{\frac{(n_{2\,post} - 1)s_{2\,post}^2 + \ (n_{1\,post} - 1)s_{1\,post}^2}{(\ (n_{1\,post} \ + \ \ n_{2\,post} \ - 2)}}$$

Where $n_{1\,post}$ and $n_{2\,post}$ are the sample sizes of treatment group and control group respectively for the posttest. $s_1^2$and s_2^2 are the variance of treatment group and control group respectively in the posttest.

Table 5 summarises the studies included in this thesis. ES shows the calculated effect size for each study. For P4 we used Cohen's d. The effect size was calculated from mathematical performance tests.

Table 5: Studies included in this thesis

Grade	Setup	Duration	Year	N	ES	Tests conducted	Paper
1	Pretest-posttest	10 weeks	2013	40	0.55	Mathematical performance	P1
3	Pretest-posttest	18 weeks	2015	37	0.60	Mathematical performance	P2
1	Pretest-posttest	29 weeks	2015	80	0.64	Mathematical performance, arithmetic fluency*	P3
2	Posttest	2 years	2015	82	0.43	Mathematical performance, arithmetic fluency	P4
3	Pretest-posttest	15 weeks	2018	140	0.33	Mathematical performance, arithmetic fluency	P6

*Arithmetic fluency only in posttest

For meaningful interpretation, we used Cohen's (1992) suggested classification for effect size of 0.20 is small, 0.50 is medium, and 0.80 is large. According to this classification studies P1, P2, and P3 yielded a medium effect size. For the two remaining studies, P4 and P6, the effect size was small. The weighted average effect size for all five studies was 0.47, which is considered small but almost medium. The average was weighted by the sample size (N).

4.5 Teacher perceptions

At least in Finland, teachers are key classroom actors who decide which pedagogical approaches to use and how to integrate them in the lesson. Even with limited autonomy, teachers are responsible for creating and sustaining routines in class. For this reason, we have paid great attention to teachers' experiences and opinions on ViLLE. One easy way to get feedback, is through trainings (Kurvinen, et al. 2018). We also gathered feedback through multiple channels: email, built in feedback forms, and by phone support. In addition to those, we have conducted surveys to get more information of teachers' opinion and usage patterns. P5 focuses on teacher feedback.

According to the responses, almost 65% of the respondents reported they use ViLLE at least once a week, which is the default recommendation by our trainers. Almost all teachers (87%) use ViLLE once in a two week time period, which could also include homework every other week. Almost 60% of respondents assigned homework, at least some of the time, from ViLLE. The longer the teacher used ViLLE, the more likely they were to assign homework. This is of course natural. When teachers gain confidence, they are more likely to expand the usage to a higher level.

The usage of more advanced features, like differentiation, showed mixed results. Some teachers praised them while others reported not remembering the features, or they hadn't realised that they could use them as well. Using preliminary and bonus groups for differentiation was more popular (67.8%) than adjusting trophy levels (50.4%).

In general, teachers seemed satisfied with the difficulty level of the exercises (P5). More specific feedback was provided every now and then for certain exercises being too difficult/easy, but on average teachers seemed satisfied. They also report finding suitable content fairly easily, which is our goal for easing teachers' workload. The way our content was created in collaboration with teachers should yield suitable content. However, in Finland teachers can choose their teaching material and pedagogics freely, which might cause challenges and a lot of variation in their needs.

Teachers need to attend a training before they get access to ViLLE. There are various models ranging from webinars and live trainings to collegial support (Kurvinen, et al. 2018). In the survey, we wanted to get the teachers' perception on how prepared they are to use ViLLE and DLP. 91% of respondents reported that they are fairly confident, confident, or very confident of their skills. This shows that there is still room for improvement for training and advertising new features according to previously mentioned comments of not knowing some features. The platform keeps evolving and some features might have been introduced after initial training was given to a teacher.

In addition to training, we think it is important that teachers can contact our team if they have technical or practical questions. We have multiple channels: email, build in feedback form, phone and trained colleagues in schools that can provide support. We got many reports stating not having needed help (yet) or being the only teacher in their school currently using ViLLE. Excluding these, 94% of teachers seem to be at least somewhat satisfied on received support. Many teachers seemed surprised on the fact that our support team can be reached and they were able to react and resolve problems.

The high number of regular usage and positive feedback concerning the content, support and training show high teacher satisfaction. This being said, teachers do report some technical difficulties. Some of the concern outdated software on school devices, some problems are caused by school infrastructure but there are also clear technical problems for example in responsiveness of some exercise types. All this feedback was welcomed and guided the continuous development.

5 Discussion

The experience of building the entire DLP, from the ground up, has been very informative and exciting. Research and evidence are important for obvious ethical reasons, but also for motivation and engagement of researchers and teachers. The close collaboration between researchers and teachers has brought theory and practice closer together. Working collaboratively helps researchers understand practice and helps teachers see the theoretical background. The collaboration is not only important in the early stages, but constant communication and collaboration is valuable, and valued by teachers (P5). The close connection to teachers helps developers and researchers understand the needs in schools and lessons and how those needs evolve.

Previously, we measured the difference between the treatment and the control groups using the mathematics performance test, and in some cases we used the arithmetic fluency test. We established a baseline by validating the similarity between the groups before starting the treatment, and then we compared the means of test scores after all treatments. In all cases except in fluency test in P4, the treatment group outperformed the control group statistically significantly (P1, P2, P3, P6). The midtest-posttest comparison in P3 also suggests that students using TEL reached higher levels of knowledge sooner. TEL also seemed to help all students regardless of their skill level (P3). However, this needs further research.

In this thesis, the effect size analysis was included as a new analysis to measure the impact of TEL (Table 4). The weighted average effect size over all studies included in this thesis was 0.47, ranging from 0.33 to 0.64, which yields small but almost a medium effect size. The result is in line with previous studies conducted by Chauhan (2017) and Harskamp (2014), but is clearly higher than in two other studies conducted by Cheung et al. (2013)

and Li, et al (2010). The effect size further strengthens the previous analysis reported in the research papers, and shows TEL can be beneficial for learning. Stephan (2017) conducted a year-long study on a very similar platform Mathletics, containing many of the same elements as ViLLE. However, there was no statistically significant difference in students' overall learning performance, only in computational test scores. The mixed results compared to papers presented in this thesis, and the comments presented by teachers, that they could have utilized Mathletics even better, yield the importance of careful and meaningful integration to actual school life and teachers' needs.

Feedback from teachers is very positive. The growth in user accounts (Figure 16) and in exercise submissions (Figure 17) show a growing interest in ViLLE and DLP. In the teacher survey in P5 we did not ask about using the statistics and learning analytics in assessment. Questions concerning learning analytics will be added to future surveys. The learning analytics is one of the biggest added values to teachers in TEL solutions after all.

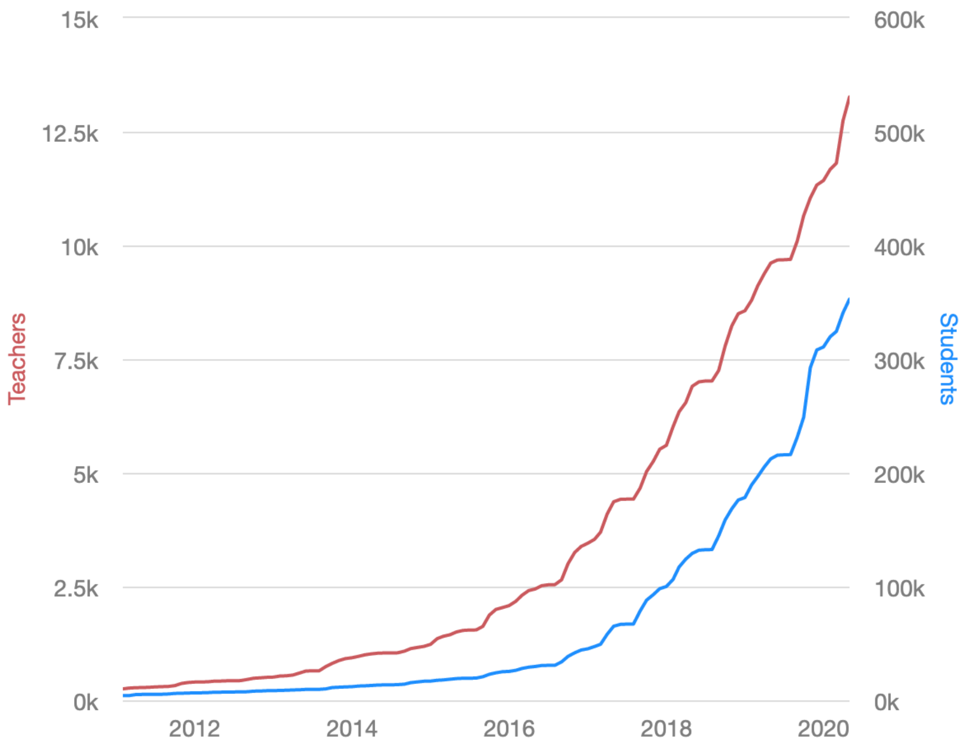

Figure 16: Number of student and teacher accounts in ViLLE since 2011

When writing this thesis, there were over 350 000 student accounts and 13 200 teachers accounts in ViLLE. This number includes all levels of education from preschool to higher education. In May 2020, the DLP was used in more than 46% primary schools in Finland. The user base seems to be growing at a steady pace, almost doubling annually. New users can participate in either training arranged by our trainer staff or by more experienced teachers. There are three levels of teachers: basic teachers (users), expert teachers and trainer teachers. Expert teachers have three accounts that they can create for their colleagues annually. This also requires the expert teacher to give proper introduction into the platform. Trainer teachers arrange similar training sessions than our staff and they have no limitations in creating accounts.

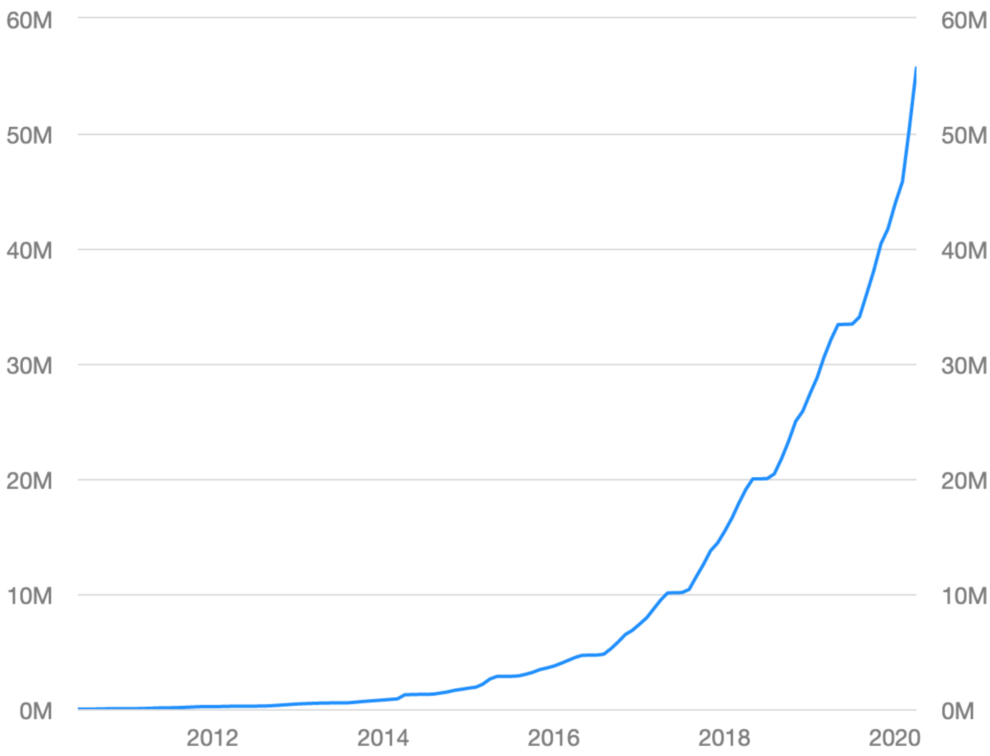

Figure 17: Number of exercise submissions in ViLLE since 2011

The number of completed (submitted) exercises has increased at the same pace as the user base. There are almost 100,000 exercise submissions on a daily basis, which translates to almost two million monthly submissions. The volume of data aggregating and the close collaboration with many teachers creates unique opportunities for future research.

5.1 Study Limitations

The findings presented in this thesis and the papers included are limited to observing the mathematics learning performance and arithmetic fluency in grades 1-3. Primary school in Finland covers grades 1-9. This needs to be considered, when the results are generalised. The instruments for measuring learning are based on existing instruments, but are adapted by the researchers. The internal validity of the used test has been verified and reported in P6, P4 and P3. The tests used in P1 and P2 are based on the same principles as the tests used later but Cronbach's alpha for internal consistency has not been reported in these papers. Furthermore, papers P1 and P2 compare only the averages of the control group and treatment group between the pre-test and post-test. The averages do not exclude students who participated only in one test (either pre-test or post-test) but all students are included. Papers P6, P4 and P3 do also address this shortcoming of P1 and P2. There was no pretest in P4 to confirm students' performance before the treatment. However, the result in P4 follows the same trend as other studies - P1, P2, P3 and P6.

The used tests only present one of the many possible points of views in assessing students' learning. Some other possible approaches could be measuring the transfer effect, socioemotional effects or maybe just comparing the marks given by the teacher at the end of the semester.

There was some variation in the effect size analysis. According to Li, et al. (2010) using non-standard tests typically yields higher effect size. The effect size of 0.33 (P6) seems low compared to other analysed studies. One reason could be the short experiment time (15 weeks) but P1 is even shorter, 10 weeks, and it still yields better results. P6 is the only study conducted in a foreign language and had the least contact with researchers. The lesson structure is also different compared to previous studies. Students before P6 had around 20 exercises in a lesson and 70% minimum requirement, compared to closer to 30 exercises and 50% minimum requirement. These and the possible mismatch between local curriculum and Finnish curriculum in such a short study could be possible explanations, but these need further investigation to be verified. The students in P2 treatment group were exposed to very early iterations of the DLP and this might have an effect on the results. The largest effect size was achieved in P3, which was also a relatively long study and with many students. These students started with a more complete feature set compared to P4 students. In all the studies, the teacher's effect and the way DLP was implemented might be one explanation for fluctuation in results. The teacher has the most important role in motivating students and building routines in class.

The results of P5 are based on a teacher survey. Conducting survey studies has always limitations of including only the enthusiastic teachers who are deeply involved in the platform.

Even with the limitations presented here, the various studies show similar results thus laying a solid foundation for the conclusions presented in the next section.

6 Conclusions and Future Work

Education and education technology are complex fields to study. It is often impossible (and by no means practical) to find comprehensive solutions to problems or unambiguous answers to questions. Rather, we need to come up with good enough practices that will, in time, give way to improved or totally new solutions. In this thesis, I tried to answer three research questions. The questions and the related results in this thesis are summarized below.

RQ1. Do regular technology enhanced lessons improve mathematical performance?

Based on all experimental research papers included in this thesis (P1, P2, P3, P4, P6) there is clearly a statistically significant improvement in students using TEL, hence we clearly improved students' mathematical performance. The enhancement is shown in multiple grades and in multiple setups. The effect size presented in this thesis (Section 4.4) further strengthens these findings.

RQ2. Do regular technology enhanced lessons improve arithmetic fluency?

P6 and P3 show high support that technology enhanced lessons improve arithmetic fluency. Even in P4, where the increased difference in speed was not statistically significant, the difference in errors made was statistically significant. In all cases (P4, P6 and P3) there is clear evidence that technology enhanced lessons will reduce drastically the number of mistakes. These results show that technology enhanced lessons will improve arithmetic fluency.

RQ3. What are the teachers' perceptions regarding using technology enhanced lessons?

> The very positive user feedback presented in P5, and the fact that the majority of teachers use the learning path content regularly, shows that teachers are willing and happy to use the learning path. The growth in number of users presented in Section 5 (Figure 16) shows great traction and interest towards the learning path. The fact that 98.9% of the teachers using the DLP are willing to use the platform yields wide acceptance across the users and has already surpassed our highest expectations (P5). There is clearly willingness and need to use such solutions and the learning path seems to fit teachers' needs.

The data aggregating in ViLLE alone creates vast research possibilities. In many cases, using technology aims to optimise the task at hand. In case of learning, good optimisation would be to provide just the right amount of practise. The question is how many exercises would be enough to get the optimal learning outcome based on the amount of work done by the student. Is there a limit where extra work would not provide substantial benefits? What other factors are there than just the number of exercises completed, when learning is optimised? In addition to already existing adaptive features, further adapting the content to students' needs would be a natural next step for research and collaboration with teachers. The question is: How to handle highly personalised learning in a structured school environment or is it even something that we are looking to achieve? How much personalisation is adequate?

In this thesis I have discussed quite strictly the effectiveness of DLP. There are many interesting aspects that should be further research, like the correlation between DLP activity and improved test results or does the genders have any differences in the results. The possible differences between genders was briefly observed in P3. No statistically significant difference was found either in the pre-test or in the post-test but this result only scratches the surface.

One clear limitation of the DLP currently is that it focuses on practicing already learned skills instead of delivering instructions. A next logical step would be to include, even a short, instructional section to each lesson. This would help students to learn more autonomously but it could also distribute best practices for mathematical instructions for a wide audience of teachers.

Based on my experiences, learning analytics is also something that should be further developed and researched. We started by simply showing raw numbers, like scores or time used. These numbers were later transformed to graphs for better readability and later we even implemented colors to group students' learning performance (Figure 12.) This kind of evolution is needed to help teachers interpret the statistics and actually provide them with analytics and later even suggest actions based on results.

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