Creating an automated learning environment for medication calculus: results from a pilot test*

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Abstract

A pilot test was carried out using ALM, a novel online learning environment for medication calculations, set up on the automated assessment system STACK. During more than a decade, STACK has been successfully and widely used for studying science, technology, engineering, and mathematics in many higher education institutions. However, the suitability of STACK for learning medication calculation has not been studied even though e-learning environments (comparable to STACK) are becoming common also within education for healthcare professions.

In this study, we report and discuss the use of ALM and workshops in the light of the participating students' experiences and also by combining study results with survey data and log data from the learning environment.

Keywords: STACK, medication calculation, ALM, e-learning

1 INTRODUCTION

The importance of reliable calculation skills among healthcare professionals has long been identified, and the topic has received increasing attention during the last decades (e.g., Grandell-Niemi et al., 2003; McMullan et al., 2010; Røykenes & Larsen, 2010). At Arcada University of Applied Sciences (hereafter Arcada), this need induced the development of the web-based environment "Sigma" for practicing and testing medication calculation skills (Dahl & Ståhl, 2010; Leikas et al., 2012). Sigma was in use during the period 2002-2016, when it was closed down due to the outdated platform technology, which made further development impractical. However, the basic features, pedagogical ideas and materials were utilised in the next development phase as described below.

The ÄlyOppi Project, funded by the Ministry of Education during 2018-2021, aimed at extending the use of e-learning environments in university-level education in Finland. The project "Lääkelaskenta" (in English, medication calculation) was part of ÄlyOppi, and its purpose was to improve the mathematical proficiency of students within various healthcare professions. In order to achieve this goal, we utilized the automated assessment system STACK (originally developed for general mathematical content) to

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develop and evaluate novel e-learning materials that were embedded in STACK as a Moodle question type. The purpose of this article is to describe the pilot study built upon the STACK-based exercise set ALM (short for "Arcada LäkeMedelsräkning") for learning medication calculations at Arcada. To a large extent, ALM was based on study materials and pedagogical ideas in the previously mentioned in-house e-learning environment Sigma. We focus on analysing nursing students' experiences and performance using the data from the pilot tests. We also comment on how the introduction of an e-learning system for healthcare students takes place. Both challenges and successful experiences are reported in terms of statistics and open feedback from the students.

The proposed e-learning solution (i) enables healthcare students to practise medication calculations either independently or under the guidance of a teacher, (ii) supports students who require more practice, and (iii) is usable for graduated nurses who wish to enhance their professional skills in medication calculations and/or for re-certifying their competency, e.g., when returning to the profession after some kind of absence. The strength of the solution is the capability of providing immediate feedback and even instructing the student based on the identification and categorization of occurring errors.

2 BACKGROUND

2.1 Learning medication calculus in healthcare professions

The mathematical/arithmetic competencies within healthcare professions belong to the field of primary school arithmetics: i.e., addition, subtraction, multiplication, division, and elementary applications such as linear equations, percentages and fractions. In addition, logical reasoning and deduction are required since the situations in practice often have the character of ill-defined problems. Since STACK was originally developed for the needs of Science, Technology, Engineering and Mathematics (hereafter STEM) students (Rasila et al., 2010), it has more than sufficient ability to express and process mathematical content for medication calculations (Sangwin 2013; Sangwin & Harjula, 2017). However, applying STACK to such calculations is quite a different type of effort since mathematical skills and requirements in healthcare professions differ considerably from those in science and technology.

The true challenge in learning medication calculations – as opposed to requirements in, e.g., engineering – is that the required proficiency must be on such a level that guarantees no mistakes at all. Obviously, even a competency level as high as 99 % does not exclude the risk of serious incidents in patient work. The teachers' challenge is further exacerbated by the fact that not all students have been supported in identifying their personal mathematical orientation, and they may require a lot of training to achieve the required proficiency level. Several studies report low levels of proficiency in medication calculation both for nursing students and registered nurses as pointed out in Dahl et al. (2014) and Hurley (2017). An e-learning environment (such as STACK) appears as an inexpensive and scalable, attractive complement to traditional studying methods, and can be used both in class and for self-study.

In order to achieve success, the e-learning platform and the materials developed on it must be authentic, relevant, appropriately challenging and, preferably, subjectively appealing to nursing students (Dunnington, 2014; Wu et al., 2014). Variations in attitudes towards e-learning are interesting as they reflect its suitability to the target group. It is also valuable to understand what kind of students are not likely to benefit from the possibility of using an e-learning environment.

To support students' learning, we applied the so-called "4 Cs" model where the acronym 4 Cs stands for the four-step structure of medication calculation, namely Compute, Convert, Conceptualise, and Critically evaluate (see Dahl et al., 2014; Johnson & Johnson, 2002). The capability of the 4 Cs model to capture and characterize the usual error types in medical calculation in an accurate and objective manner has been confirmed in Dahl et al. (2014). Thus, building upon the experiences from the Sigma environment, the material development in ALM is also rooted in the pedagogical 4 Cs model.

The 4 Cs model contributes to improving students' Perceived Self-Efficacy (PSE) which is related to social learning theory by Bandura (1977). More precisely, PSE refers to the student's belief in herself, and her ability to learn and to successfully carry out a task. There is a significant relationship between nursing students' ability to perform medication calculations, mathematics self-efficacy, and computer-assisted instruction received as pointed out e.g., by Hodge (2002). PSE is related to motivation to learn and to ask for advice which are notions and activities affected by the introduction of e-learning components into education.

We conclude that the development of e-learning systems for medication calculations has a long history at Arcada since 2002. The main pedagogical concept of ALM was already present in the earlier Sigma environment but has previously not been implemented on an e-learning framework for mathematics such as STACK.

2.2 The current study

The current pilot study is the first one relating to the ALM environment. Therefore, the aim of the study was to explore how the students experienced ALM and the workshops in general. From a pedagogical perspective, the aim was to explore which of the elements in the 4 Cs model are supported by ALM and by the workshops, respectively.

3 MATERIAL AND METHODS

The pilot study involved one cohort of students, and since the ALM environment was used for the first time, there were no earlier similar studies on how materials based on STACK meet the requirements of medical calculation training.

3.1 Participants and modes of learning

The original test subject population consisted of 95 students in emergency care, nursing, public health nursing and midwifery. Personal user accounts were created for access to the ALM environment, where both the user interface and all content was available in Swedish, Finnish and English.

Studying during the course consisted of classroom workshops under the guidance of a teacher (one of the authors). The students were given study material with correct answers but without solutions. Solutions were demonstrated in class. Students also had access to a compendium and to exams from previous years. Access to the ALM environment was offered to all students as an external service, separate from the university's e-learning environment. Using ALM as well as participation in the workshops was voluntary.

3.2 Data collection

The data for the study was obtained from three sources:

- Basic participant data from the university's student registry,
- Activity data from ALM/STACK-Moodle environment,
- Two sets of survey data collected using the open-source online survey tool LimeSurvey (2020), hosted and administered by Arcada.

Data from student registry

To target the survey to the correct respondents, basic participant data were obtained from the university's student registry: name, email address, year of birth, gender, previous education, enrolment year, degree programme. The demographic data were collected to enable categorisation and comparisons across groups.

The ethical permission for the study was granted by the research vice rector at Arcada. The participants were informed about the study, and their consent was confirmed in the beginning of the surveys. All data were pseudonymised.

Study materials and log data in ALM

The ALM environment provides medical calculation exercises containing eight problems and where each problem is presented according to the standardised structure that was developed already in the Sigma environment (Leikas et al., 2012). The structure comprises (i) background, (ii) the drug to be used, (iii) prescription and (iv) the actual problem, as illustrated in the sample screenshots (Figures 1 and 2). When responding, the student enters the amount as a numeric value and the units as a textual expression into the input field. ALM recognises and separates the amount and the unit, both of which are required and assessed.

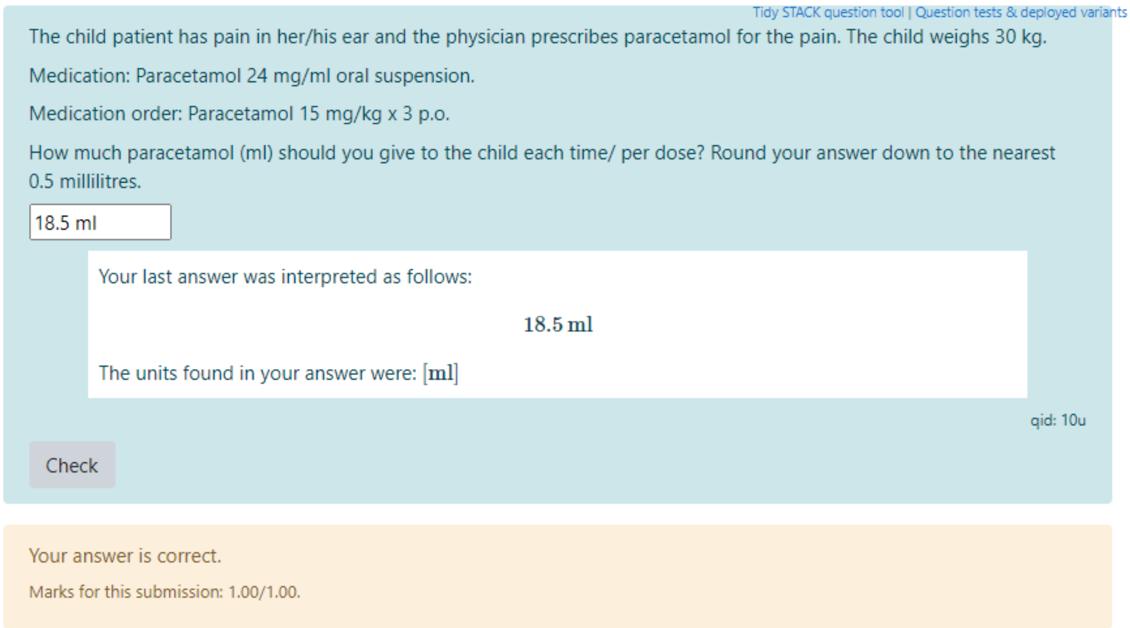

Figure 1. Screenshot demonstrating a calculation problem involving body weight based dosation and dosis calculation based on the dosation and the concentration of the drug.

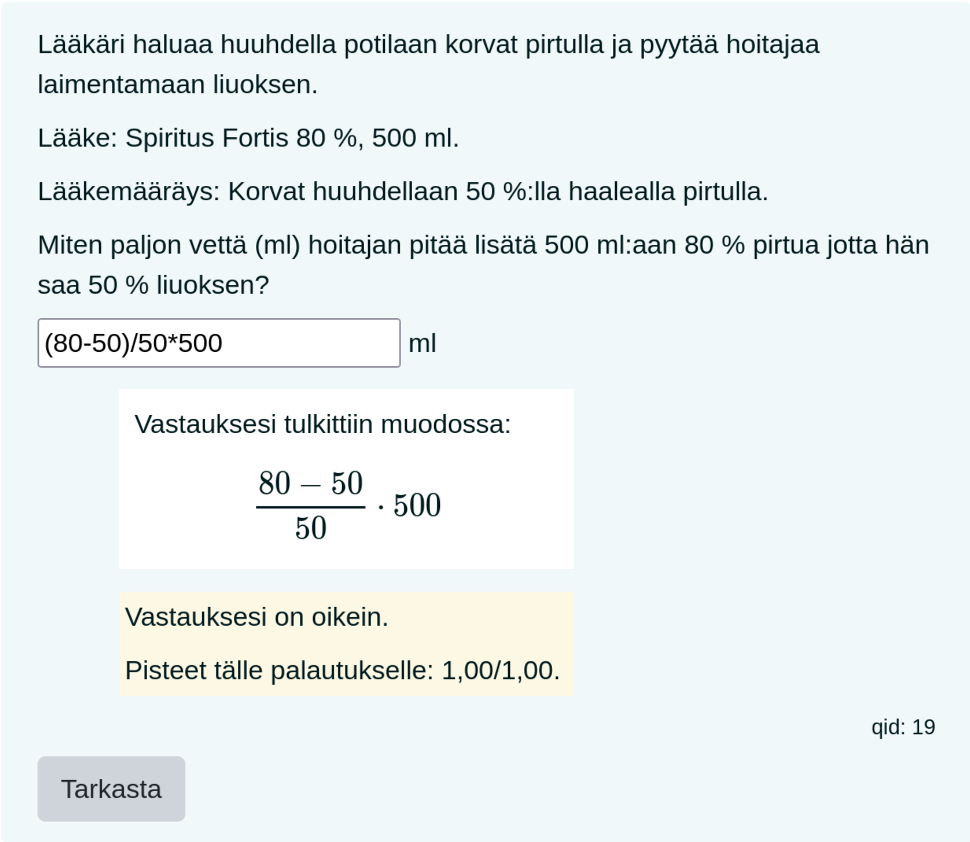

Figure 2. Screenshot demonstrating how ALM handles the response entered as a formula.

Besides entering amount and unit, ALM also allows the answer to be entered as a formula, applying standard arithmetic format and syntax (Figure 2). After submitting the answer, ALM provides immediate feedback, not only about the answer being (in)correct but also about, e.g., missing or incorrect unit.

During student activity, ALM collects log data containing exercise-based information about which problems were included in the exercise, points given for each problem and the length of time the student spent on the exercise. These data are further used to calculate the exercise score, minimum and maximum scores, and the number of exercises for each student.

Survey data

For the survey, the students were invited to participate by personal email messages in which they were informed about the aim of the study and that participation was voluntary.

Students' opinions, attitudes, and experiences were surveyed in terms of two surveys (i.e., pre- and post-course). The students rated all attitude questions on a 5-point anchored scale ranging from strongly disagree (1) to strongly agree (5). The pre-course survey consisted of at most 17 questions (the exact number depending on the student's choices) where the students provided information about their background education as well as familiarity and earlier experiences about online learning. Among these questions, each student answered at most five questions about general e-learning and e-learning in the context of mathematics, suitable for statistical analysis. In four open-ended questions, the students were asked to verbally describe their expectations on and their goals for the course.

The post-course survey comprised at most 22 questions, including five open-ended questions. There were two questions about the way the student took part in learning activities in terms of self-study, workshops led by the teacher, and peer learning in, e.g., a study circle. There was a question on the preferred mode of independent learning and the experienced sufficiency of support received from the teacher and peers. Three questions concerned the practical methods for solving the problems (pen and paper, calculator, computer). The students were asked which sources they used for independent learning (book, lecture notes, ALM, and previous exam questions), and how they experienced the course work load.

Out of the five workshop-related questions, three attitude questions involved the learning activity level, experienced benefit and introspection on putting effort into studying. In addition, two open-ended questions regarded participation in workshops and suggestions on how to improve them.

Seven attitude questions and two open-ended questions concerning the ALM system were asked. Those who did not report having used ALM were additionally asked about reasons for not using the system.

3.3 Data descriptors and analysis strategy

Out of the 95 participants, 88 had started their studies in 2019, 5 in 2018 and 2 in 2016 or 2017. The mean age was 22.9 and the age median 21.

Out of all the participating students, 68 took part in the pre-course survey. Out of these, 45 students had a degree from an upper secondary school, and 23 students had a degree from a secondary level vocational school. Three of the students had received their degree from abroad. 54 students answered at least one of the questions in the post-course survey, and 49 of them answered all questions. Based on log data, the ALM system was used by 40 students. Out of the 54 students who answered the post-course survey, only 13 reported having used ALM even though 29 of them actually had a record of activity in ALM. Out of the 95 students taking the course, 52 passed the final exam on the first try, 20 passed on the second try, 4 passed on the third try, and 5 passed on the fourth and last try. Nine students took but failed to pass the exam, and five students interrupted the course.

After data collection, the three data sub-sets were merged and following that, the total data set was pseudonymised. In order to respond to the research questions, the attitude items were analysed regarding distribution and to some extent, correlations were explored using the statistical software SPSS (2020).

4 RESULTS

4.1 ALM as a learning aid

Among those who had used ALM, it was generally experienced as a useful learning aid with 81% rating the ALM exercises with the grade 4-5.

Out of those who had used ALM at least once and made at least one exam attempt (n=39), 95% passed the course exam on the first or second try, whereas the corresponding proportion among the non-users was 83%. The results also show that a high score in ALM predicted passing the course exam on the first or second try. Out of 39 students, 27 reached a score of 7-8 points in ALM and out of these, 24 passed the course exam on the first try and the remaining 3 on the second try. Expressed as correlations, a high score in ALM correlates with passing the exam with few attempts ($r_s(39) = -.423$, $p < .05$).

4.2 The workshops

All students did not respond to the question about workshops, but out of those responding, 44 reported having participated at least once. Out of those assessing the workshops (n=42), 74% rated them as supporting their learning with the grade 4-5. Those experiencing the workshops as useful also invested in them so that there was a positive correlation between perceived support and investment in the workshops ($r_s(39) = .45$, $p = .003$). Correspondingly, there was a negative correlation ($r_s(38) = -.76$, $p < .001$) to the opposite claim of not investing enough in the workshops. Out of those reporting their workshop participation, 77% passed the exam on the first try. Among these were also all those who had not participated in any workshops and mostly those who had participated in only one or two workshops.

In their responses to the open-ended questions, the students expressed positive comments about the workshops in general. Specifically, they valued being organised in level-based groups, which allowed adjusting the pace. Also, the students valued that the workshops were organised in smaller groups, which allowed discussions about the mathematical methods to solve the medical calculus problems.

Those who used ALM participated slightly more in workshops but the difference is not significant, possibly due to small sample size.

4.3 Dealing with math problems

Out of the participants, 52 responded to the question about using paper and pencil or a calculator when solving problems. Out of these, 75% reported always using paper and pencil, whereas 50% reported always using a calculator. About 44% always used both but otherwise, it is not possible to discern a pattern in this rather small sample.

Using ALM or printed materials for practicing seems to divide the students. Out of those who used the compendium (48) or old exams (46), only about a fourth reported having used also ALM; that is, the majority of those using printed materials did not use ALM.

5 DISCUSSION

STACK-based e-learning has been used for teaching university-level STEM subjects for over 15 years by now. Even though it is difficult to quantitatively assess the success of this relatively novel learning method in terms of learning outcomes in technical universities, the popularity of e-learning and automatic assessment shows no signs of abatement in STEM teaching. However, the suitability of STACK-based e-learning in other areas (such as healthcare education addressed in this work) cannot be concluded from experiences in STEM subjects, mainly since the professional contexts are totally different, and perhaps also due to differences in the student populations. We proceed to discuss the related observations from the point-of-view of learning medication calculations.

5.1 ALM as a learning aid

The students were given the opportunity to practice medication calculations in ALM but they were not rewarded for using it, e.g., by giving exercise points as a partial score of the course. The reason for this practice is that only the final exam in medication calculations counts since the student will have to achieve the full score to pass the course. Students were, however, encouraged during the workshops to use ALM, but this encouragement, of course, reached only those who took part in workshops.

Comparing the popularity of ALM and workshop studying, a similar level of student satisfaction was reported. Furthermore, there is no significant difference between the number of students using ALM (n=39) and taking part in workshops (n=42). Carrying out medication calculations is a skill that requires practice since no mistakes at all are tolerated even though the mathematics itself is relatively elementary. Much emphasis is on understanding the problem setting and respecting the requirement of precision. As an e-learning environment, ALM is quite demanding in these respects. It is likely that practicing in ALM plays a role in developing self-confidence for the final exam even though this was not explored in this study.

Seven answers were obtained for the open-ended question about reasons for not using ALM. One student reported not having any need for practicing in ALM, three students reported using old exams or a previously compiled compendium, two had forgotten about ALM and one reported having difficulties opening ALM.

5.2 The workshops

The popularity of workshops is on a good level, and the active participants experienced them as useful. It should be observed that workshops are a form of social activity (in contrast to ALM) enabling collaborative learning and where encouragement, motivation, and support can be provided to those who need it. It is, however, possible to pass the final exam without taking part in workshops. The workshops emphasize learning as a social activity, where discussion and comparison of different approaches helps each student to recognise which approach is most appealing.

It is not possible to discern a connection between workshop participation and exam success (see section 4.2). Rather, the results may suggest that those who participated in workshops would have succeeded in the exam anyway, whereas those who would have profited from the workshops did not participate.

5.3 Learning in online environments

There is a technological disruption going on in teaching methods in Finland. Some of the students have learned to use the digital "Abitti" system in upper secondary school. Working with paper and pencil is no longer as common as it used to be even though computing on paper remains an important activity in primary school. ALM may well be experienced as both psychologically and technically demanding by students for whom it would be their first e-learning experience. Unfortunately, the survey data does not allow making such conclusions since not all students used ALM.

In the context of medication calculations, three different types of problem-solving strategies have traditionally been taught at Arcada. The motive for this is to support each student to find the way of thinking and calculating that is most understandable and suitable to herself. There was one survey answer where the student expressed frustration for having different ways of thinking about the same problem. In its present form, the automatic assessment logic of ALM does not conform to different solution strategies but it only classifies the way how the given wrong answer is wrong. Neither does ALM provide a model solution at the end. However, ALM provides immediate feedback to the same (numerical) version of the problem that was chosen for the student. A fair amount of development work would be required to improve ALM so as to take account of different problem-solving strategies.

It is a general observation that students with upper secondary school background are more accustomed to independent studying compared to students with background from, e.g., vocational schools.

The pilot test described in this article gives rise to a number of qualitative observations from teacher's side. In particular, considering the workshops and ALM as collateral and complementary ways of learning is a fruitful vantage point. In terms of the 4 Cs model (Johnson & Johnson, 2002), we conclude that the contact teaching in workshops seems to be best suited for the "critically evaluate" and "conceptualize" aspects whereas ALM is a tool for the remaining two aspects of 4 Cs, namely "compute" and "convert". In its current version, ALM is not capable of supporting critical evaluation and conceptualization. It is likely that future technological advances in e-learning frameworks (such as STACK) may make it easier to produce more intelligent and interactive materials, better satisfying the requirements for critical evaluation and conceptual understanding.

In the future, the STACK exercises will allow carrying out learning analytics on data accumulated in the STACK environment. This will hopefully enable the application of the 4 Cs model (Johnson & Johnson, 2002) in creating feedback that is more tailored, thus supporting students in identifying their strengths and weaknesses which, in turn, will support their learning and mathematical self-efficacy (cf. Hodge, 2002).

The aim of collecting and analysing learning data is to create evidence for improving and developing not only e-learning materials but the learning methods in general. The long-term goal is to develop a modern STACK-based e-learning environment and gamified, deeply interactive learning materials that allow automatic assessment and categorisation of the students' answers using, e.g., deep neural networks (DNN) and data mining.

5.4 Consequences for educational practice

We wish to emphasize that e-learning environments for independent studying are not intended to be a replacement for classroom teaching or an instrument for plainly getting better learning outcomes. The flexibility of learning, provided by ALM around the clock and just before final exams, has value in itself. The teacher using e-learning perhaps carries out fewer "drill training sessions" than before, but her efforts in materials development and course management correspondingly increase. The ongoing technical development of e-learning platforms widens the possibilities but also further increases the requirements in materials development.

We cannot ignore the fact that the resources for providing workshops are limited and typically, a relatively small portion of students require most of the teacher's attention during workshops. A part of drill practicing can take place, e.g., in an online environment such as ALM, which will free up resources for classroom teaching in situations where self-directed learning in an online environment cannot be of any assistance. Our results regarding ALM scores, workshop attendance and exam attempts support the empirical observation that students' mathematical skills level vary strongly. Therefore, most of the value of using ALM parallel to workshops lies in the potential to support each student's personal learning path. Further, more effort should be invested in pretesting the students' mathematical skills in order to target those with weak skills and encourage them both to participate in the workshops and to use ALM for practicing.

Medical calculus proficiency requires mastering all four "Cs" and in addition, all students have to achieve 100% proficiency. A digital environment such as ALM may support drilling the Computing and Converting aspects but still, if Conceptualisation and/or Critical thinking are deficient, the proficiency is basically zero and the risk for patient injuries high.

Our conclusion is that a learning environment such as ALM is a valuable tool in combination with classroom teaching and workshop activities. The combination of these learning activities will support the individual learning paths, and applying the 4 Cs conceptualisation will assist in identifying which Cs require support and strengthening.

We conclude by pointing out that the pilot test reported in this article was arranged in autumn 2019 before the first wave of the COVID-19 pandemic in Finland. At the pandemic outbreak, a large part of all higher education was transformed into various forms of online remote studying at a very short notice. We expect that this change will have permanent consequences on how e-learning platforms are used in higher education.

6 REFERENCES

Bandura, A. (1977). *Social Learning Theory*. Oxford, England: Prentice-Hall.

Dahl, B. & Ståhl, T. (2010, May 20-21). Improving skills in dosage calculation. Poster presented at the 1st Nordic Patient Safety Conference, Stockholm.

Dahl, B., Ståhl, T., Malinen, J., Rasila, A., & Tiitu, H. (2014, April 4th). Diagnosing nursing students' errors in medication calculations. Designing a method based in the 4 Cs teaching model for analysing mathematical proficiency. In J. Viteli, A. Östman. *Tuovi 12: Interaktiivinen tekniikka koulutuksessa 2014-konferenssin tutkijatapaamisen artikkelit.* Interaktiivinen Tekniikka Koulutuksessa 2*014*, Hämeenlinna, Finland, 82-92. http://urn.fi/URN:ISBN:978-951-44-9561-8.

Dunnington R. M. (2014). The nature of reality represented in high fidelity human patient simulation: philosophical perspectives and implications for nursing education. *Nursing philosophy*, *15*(1), 14-22. https://doi.org/10.1111/nup.12034

Grandell-Niemi, H., Hupli, M., Leino-Kilpi, H., & Puukka, P. (2003). Medication calculation skills of nurses in Finland. *Journal of Clinical Nursing*, 12(4), 519-528. https://doi.org/10.1046/j.1365-2702.2003.00742.x

Hodge, J. E. (2002). The effect of math anxiety, math self-efficacy, and computer assisted instruction on the ability of undergraduate nursing students to calculate drug dosages. Doctoral dissertation, West Virginia University.

Hurley, T. V. (2017). Experiential Teaching Increases Medication Calculation Accuracy Among Baccalaureate Nursing Students. *Nursing Education Perspectives* 38(1), 34-36, https://doi.org/10.1097/01.NEP.0000000000000097

Johnson, S. A., & Johnson, L. J. (2002). The 4 Cs: A Model for Teaching Dosage Calculation. *Nurse Educator*, 27(2), 79-83. https://doi.org/10.1097/00006223-200203000-00011

Leikas, S., Granberg, L., Ståhl, T., Kurko, T., Antikainen, O., Airaksinen, M., & Pohjanoksa-Mäntylä, M. (2012). Sigma – Lääkelaskennan oppimisympäristö: Kehittämistarpeet ja hyödyntämismahdollisuudet farmasian peruskoulutuksessa. [Sigma: E-learning environment for learning medication calculation skills: Pharmacy students' perceptions of its usefulness and development needs] *Dosis*, 28(2), 106-117.

LimeSurvey (2020). LimeSurvey v. 3.22 [computer software], LimeSurvey GmbH, https://www.limesurvey.org/

McMullan, M., Jones, R., & Lea, S. (2010). Patient safety: numerical skills and drug calculation abilities of nursing students and registered nurses. *Journal of Advanced Nursing*, 66(4), 891-899. https://doi.org/10.1111/j.1365-2648.2010.05258.x

Rasila, Havola, Majander & Malinen (2010). Automatic assesment in engineering mathematics: evaluation of the impact. *Reflektori 2010,* Symposium of Engineering Education, 37-42.

Røykenes, K., & Larsen, T. (2010). The relationship between nursing students' mathematics ability and their performance in a drug calculation test. *Nurse Education Today*, 30(7), 697-701. https://doi.org/10.1016/j.nedt.2010.01.009

Sangwin, C. (2013). *Computer Aided Assessment of Mathematics*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199660353.001.0001

Sangwin, C & Harjula, M. (2017). Online assessment of dimensional numerical answers using STACK in science. *European Journal of Physics*, 38(3):035701. https://doi.org/10.1088/1361-6404/aa5e9d

SPSS. (2020). SPSS 26.0 [computer software]. Chicago, IL: SPSS Inc., IBM Corporation.

Wu, X.V., Heng, M. A. & Wang, W. (2014), Nursing students' experiences with the use of authentic assessment rubric and case approach in the clinical laboratories, *Nurse Education Today*, 35(4), 549-555. http://dx.doi.org/10.1016/j.nedt.2014.12.009

Älyoppi project. https://tim.jyu.fi/view/hankkeet/alyoppi/matematiikka#matematiikan-osahanke