Scientific paper

The Comparison of the Speed of Solving Chemistry Calculation Tasks in the Traditional Way and with the use of ICT

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Abstract

Efficiency of time use is a key factor in chemistry calculation tasks, affecting both, personal and professional domains. This study is dedicated to finding the fastest methods for accomplishing chemistry tasks. Our investigation delves into the comparative temporal outlays made by students as they engage three different approaches: using an electronic calculator, a basic calculator app on a smartphone, and a desktop computer calculator. As part of our research, we examine a cohort of 52 Slovenian university students, preservice teachers who were actively enrolled in chemistry and related science programs, spanning the academic years of 2019 and 2022. The results from 2019 show that students can solve the chemistry tasks most quickly using electronic calculator and take the most time to calculate the tasks using smartphones (Δ_{mean} = 133 s; Δ_{SD} = 5 s; Δ_{min} = 97 s; Δ_{max} = 131 s). An even larger difference is observed from the 2022 study year (Δ_{mean} = 189 s; Δ_{SD} = 129 s; Δ_{min} = 170 s; Δ_{max} = 625 s). In summary, although smartphones are recognised as a multitasking device, replacing traditional single-purpose devices, they have not been able to outperform them.

Keywords: Chemistry tasks; chemistry calculations; electronic calculator, smartphones, computer calculators.

1. Introduction

Solving chemical equations and calculating quantities of reactants and products, as well as concentrations of solutions, are a traditional part of virtually every secondary and tertiary chemistry class and are skills that extend beyond the chemistry laboratory[1,2] and can be considered a lifelong skill.[3] There are basically two approaches to dealing with chemical equations. The first is algebraic, when one is more interested in proportions, and the second is more "practical", when students are expected to deal with measurable quantities. While the first approach is mainly concerned with the micro level and symbolic level, the second approach is mainly concerned with the macro level and measurable quantities associated with symbolic annotations.[4] Typical examples for the first approach are stoichiometric equations and for the second approach, for example the calculation of quantities used to produce solutions by mixing ingredients. The term chemical calculations is used in the text to refer to these types of chemistry tasks, although in some cases they may be considered physics, showing the interconnectedness of the scientific disciplines.

Solving chemical calculations is anything but an easy task, because students have to switch between real (measurable) quantities and ratios and their symbolic representations,[4] using different procedures and concepts learned in other subjects (e.g., mathematics). Some difficulties can also be traced to teachers who try to teach their students, usually forgetting that what may be obvious to them was actually developed by some of the most brilliant minds of the past.[5]

Chemistry classes are compulsory for all Slovenian students in lower secondary education (8th and 9th grade of compulsory school), for students in upper secondary education and for students in many vocational education programmes, which places an additional burden on teachers, as many students lack interest, motivation and various skills to learn chemistry, including solving equations and performing calculations that are expected as learning outcomes of the courses.[6] An additional problem, especially in the early grades, is the need to apply mathematical procedures and concepts with which students are not familiar, such as negative exponents or logarithms. What does not make the problems easier is the finding that many students are not able to transfer knowledge and skills from mathematics to chemistry.[7]

Thus, to successfully teach chemical calculations to students, teachers should consider several factors at different levels of control. While teachers have very limited, if any, control over students' individual abilities and, at least in the Slovenian context, over the curriculum content prescribed by the authorities, they have almost absolute control over the methods used to teach the prescribed topics and over the application of the technology used for chemical calculations.

Typically, early in their education, students learn how to perform chemical calculations with paper and pencil, with or without the use of an electronic calculator, and later in their education they may also learn how to process data with software (e.g., structural calculations).[8] What makes chemical computing complex is that students need not only chemical knowledge, but also mathematical knowledge (initially algebra), language, graphing and information processing skills.[9] It has long been known that chemical calculations present difficulties for students, especially in molar and stoichiometric calculations[10,11] and that there is only a weak link between students' algorithmic skills and conceptual understanding of topics in chemistry, which is also related to solving chemical problems.[12,13]

In solving chemical calculations we can see two basic steps. The first is the understanding of what to do, associated with symbolic representations of substances, formulas, conventions, units of measurement, and the like, and the second part is a general ability to perform numerical operations (calculations). Both steps can be supported with or without the help of digital technologies.

Nowadays, digital technologies have become everyday companions in the professional and personal lives of teachers and students, sometimes as invisible and sometimes as visible technologies.[14] When teaching and learning chemistry in secondary schools and high schools, teachers and students tipically use computers, tablets and smartphones to investigate substances, phenomena and processes at the macroscopic level and explain them at the submicroscopic level, which can improve understanding of chemical concepts.[15,16] It is beyond the scope of this article to list all possible applications of digital technologies, but we would like to highlight some references as examples of such use. For example, Dolničar et al.[17] have developed a molecular editor for constructing and editing molecular models; Tortosa[18] provides an overview of the use of data loggers in chemistry laboratories; and the potential of artificial intelligence for chemistry education has yet to be evaluated.[19] Nevertheless, the question of whether digital technologies are ubiquitous and pervasive is one of the most common questions that arise in schools and to which there is no simple answer.[20] The question that needs to be answered is, "Is the use of computers, smartphones, or tablets always justified in schools?"

The answer to this question cannot be answered in a blanket manner, and each individual use or context of use should be evaluated and possible side effects should be considered. While the use of desktop calculators and computers is the norm in chemistry labs today, the situation with smartphones is completely different. The use of smartphones is banned in many schools or even entire school systems unless justified. It is hard to imagine someone asking students to put desktop calculators or mobile computers in a locker and punishing them if they do not. The opposite might be true for smartphones. One of the useful uses of smartphones in school could be solving chemistry problems using the smartphone calculator or searching for information about chemicals. Solving a particular task or exchanging information with colleagues while writing exams are usually the cases where the use of smartphones should be prohibited, unless the study regulations or teacher's instructions are different.

Time is a precious commodity in education, and one of the most important tasks of teachers should be time management so that they can focus their efforts on activities where they can expect to make progress in knowledge and skills. In line with Borton's reflective cycle (What?, So what?, What now?)[21] teachers should be able to identify portions of instruction devoted to chemical calculations when time is being wasted on routine procedures or tasks where mastery of the speed and accuracy of calculations cannot be further improved. Since numerical calculations can be performed with or without digital technologies, we were interested in finding out whether the use of different digital technologies can affect the time required to solve a typical chemistry task related to the preparation of solutions. Three standard options were included in the study: a) the standard paper – electronic calculator method; b) paper – smartphone calculator, and; c) paper – desktop computer calculator. In addition to the direct aim of the study, we also had in mind showing students how to use simple research methods that could later be used in their classroom practice in the role of reflective practitioners and researchers of their own work.[22]

The research question was as follows: Are there differences in the time required to solve and present chemical calculation problems between three approaches, namely a) the standard paper – electronic calculator method; b) paper – smartphone calculator; and c) paper – desktop computer calculator.

2. Methods

2. 1. Sample

The sample was 52 two-stream master level preservice teachers of chemistry and other science subject from the Faculty of Natural Sciences and Mathematics, University of Maribor, Slovenia. The sample included 27 females and two males from a population of 29 students (56%) in a 2019 degree programme and 23 students (44%), 8 males and 15 females, from a population of students in 2022. Despite the covid 19 situation, all students in both cohorts were enrolled in an equal number of chemistry subjects in which they gained experience in solving chemical equations and quantity calculations, which was part of the curriculum.

The students were randomly divided into three groups. Each group had a similar task. The time taken to solve the task is shown in Table 1.

Some of the data are missing because some students did not cooperate on all tasks.

2. 2. Procedure

1. The students were given three chemistry tasks with similar data. The students had already solved similar tasks on the same level of difficulty during the study process. Each task involved data from inorganic acid (hydrochloric acid, nitric(V) acid and sulphuric(VI) acid): the volume of the acid and volumetric flask, the acid concentration and the density of the newly prepared solution.
2. The students were randomly divided into three groups. Each group had to solve the given task in three different ways 1) using the standard paper – electronic calculator method, 2) using paper – smartphone calculator and 3) using paper – desktop computer calculator. The students who solved the tasks using the standard method (1) were also given the table with specific information about the densities of the acids in different mass fractions. The other two groups were instructed to obtain the information from the Internet (using their smartphone or computer).
3. The students read the task and then began to measure the time it took them to solve the task until they had the correct result.
4. Each group was given a new task once every three weeks. The first group solved the task with hydrochloric acid using basic calculator app on their smartphones. After three weeks, the same students were given the task with nitric acid to solve using the standard method, etc.

Text of Task 1:

We add 15 mL of concentrated 38% HCl into a 250 mL volumetric flask already filled with some distilled water (up to 1/3 of the volume) and dilute it to the division mark. Calculate the molar concentration and mass fraction of the newly prepared solution with a density of 1.010 g/mL.

Text of Task 2:

We add 20 mL of concentrated 65% HNO_3 into a 250 mL volumetric flask already filled with some distilled water (up to 1/3 of the volume) and dilute it to the division mark. Calculate the molar concentration and mass fraction of the newly prepared solution with a density of 1.036 g/mL.

Text of Task 3:

We add 25 mL of concentrated 96% H_2SO_4 into a 250 mL volumetric flask already filled with some distilled water (up to 1/3 of the volume) and dilute it to the division mark. Calculate the molar concentration and mass fraction of the newly prepared solution with a density of 1.107 g/mL.

2. 3. Statistical analyses

Statistical analyses were performed using the open-source statistical programme Jamovi 2.3.16.[23,24] Research variables were analysed for mean, median, mode, standard deviation (SD), minimum and maximum.

The assumption of normality was tested using the Shapiro Wilk test and visual inspections of Q-Q plots. If the Shapiro-Wilk p-values are $p < 0.05$, it means that the assumptions of the normality are violated.

For the analysis comparing differences between years nonparametric Mann-Whitney test was applied. Results with a significance coefficient of less than 0.05 ($p < 0.05$) were marked as statistically significant differences.

Since the assumptions of normal distribution were violated the Spearman's rho test was applied to examine of

Table 1: Measures of central tendencies of *T*kls = time needed to solve the task with an electronic calculator, *T*rac = time needed to solve the task with a desktop computer calculator and *T*mob = time needed to solve the task with a smartphone calculator.

Descriptives	**year**	***N***	**Missing**	**Mean**	**Median**	**Mode**	***SD***	**Minimum**	**Maximum**	**Shapiro-Wilk W**	**p**
*T*kls	2019	29	0	558	439	343[a]	299	322	1436	0.686	< 0.001
	2022	22	1	611	557	566[a]	235	260	1118	0.941	0.210
*T*rac	2019	29	0	685	597	507	300	401	1564	0.686	< 0.001
	2022	20	3	726	705	210[a]	277	210	1320	0.988	0.993
*T*mob	2019	29	0	691	574	419[a]	304	419	1567	0.750	< 0.001
	2022	23	0	800	674	430[a]	364	430	1743	0.760	< 0.001

[a] More than one mode exists, only the first is reported

the similarities or differences between a various approaches to solving chemical calculation problems. Additional insight was gained by applying the paired Wilcoxon signed rank test using data from an entire research sample. The effect size was calculated as Cohen's d from the value of the Wilcoxon signed rank test and interpreted according to the recommendations provided. Margins were set as follows: 0 < no effect < 0.2 < small effect < 0.5 < medium effect < 0.8 < large effect.

3. Results

As can be seen from Table 1, the chemistry task was solved fastest in 2019 and 2022 when students used an electronic calculator, and they spent the most time solving the task using a smartphone calculator. On the other hand, it is very interesting to see that the least amount of time was spent solving the task when it was calculated using a desktop computer calculator, although this method was not the fastest to solve the task on average.

To test whether the data conformed to the normal distribution, the Shapiro-Wilk test was used. If the Shapiro-Wilk *p* values are $p < 0.05$, the assumptions for the normality test are violated. The violation is given for most items, except for the *T*kls and *T*rac cases in 2022.

From the results in Table 1 we can be seen that for all approaches and in all years the median values are much lower than the mean values, and that the differences between minimum and median values are quite small compared to the differences between maximum and median values. This suggests that most students took less or normal amounts of time to solve the tasks, but a few took much more time. Those students who took the most time to solve the task with one approach also took more time to solve the task with other approaches.

The minimum, maximum, median and mean times needed to solve the task increased from the time needed to solve the task with the electronic calculator to the desktop computer calculator and smartphone calculator. The mean and median times needed for solving tasks by all approaches are longer in 2022.

In Figure 1 we visually inspect the fit of the normal distribution to the data with Q-Q plots.

Since the results of the Shapiro-Wilk test show the assumption of normality was violated, the independent Mann-Whitney test was used. It shows us that there are no statistically significant differences between years at the $p < 0.05$ level. The results are as follows: *T*kls: $U = 231$, $p = 0.096$; *T*rac: $U = 235$, $p = 0.268$; *T*mob: $U = 242$, $p = 0.092$. This test was used because different students solved chemistry tasks in 2019 and 2022.

Table 2: Correlation matrix between *T*kls = time needed to solve the task with an electronic calculator, *T*rac = time needed to solve the task with a desktop computer calculator and *T*mob = time needed to solve the task with a smartphone calculator.

		***T*kls**	***T*rac**	***T*mob**
*T*kls	Spearman's rho	–		
*T*rac	Spearman's rho	0.752	–	
*T*mob	Spearman's rho	0.579	0.590	–

Note. All correlations are statistically significant at the $p < 0.001$ levels.

The values of Spearman's rho in Table 2 show us that the correlation for all approaches is positive and *p* is significant at all levels ($p < 0.01$). These results show that the students who calculate the task faster with the specific approach also take less time on average to obtain the result with the other approach. The values of the correlation coefficients can be interpreted to mean that the connections between the methods used for chemical calculations range from moderate to high. We can interpret this to mean that in addition to differences caused by a particular technology, there are other factors at play that are not accounted for in a study design.

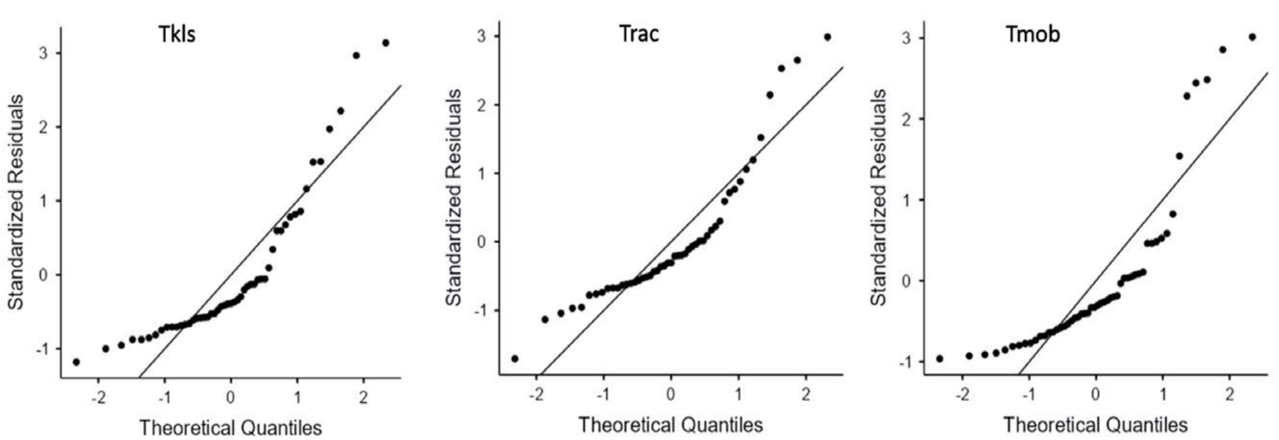

Figure 1: The distribution of data for each approach to solving the chemistry task. The data are not normally distributed.

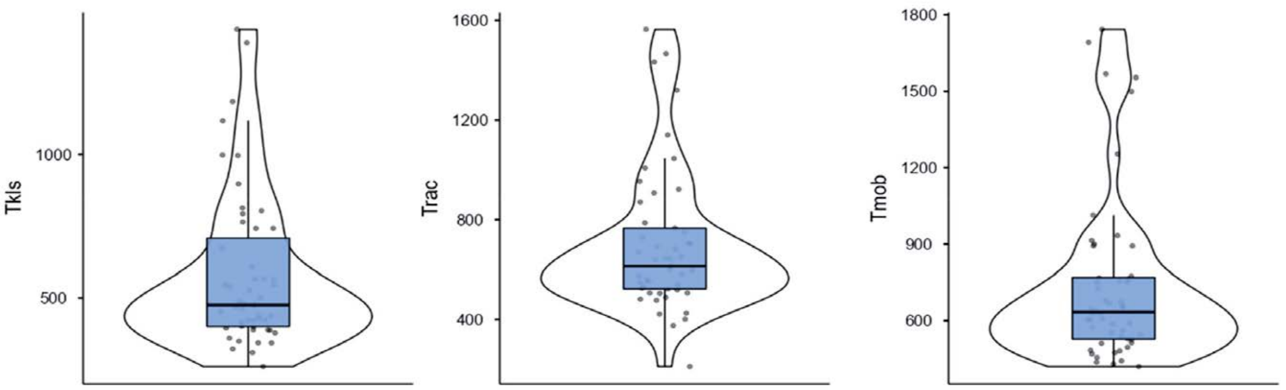

Figure 2: The distribution of the data.

The results are similarly distributed. This confirms that the students who needed more time to solve the chemistry task in one approach also needed more time in the other two approaches.

Figure 3 shows that two students actually took much more time to solve the chemistry task using the smartphone calculator than the electronic calculator and the same students also took much more time using the smartphone calculator compared to using the desktop computer calculator.

Since the comparison between years there was no statistically significant differences, we decided to perform the Paired Sample Wilcoxon signed rank test on a total sample ($N = 52$).

The result of Wilcoxon signed rank test shows that there are no significant differences in the case of *T*rac – *T*mob, $p = 0.901$, $W = 599.5$. The effect size for this analysis was found to be small ($d = 0.0212$) according to Cohen's convention.

The result shows that there is a significant difference in the *T*kls – *T*rac ($p < 0.001$, $W = 89.5$) and *T*kls – *T*mob

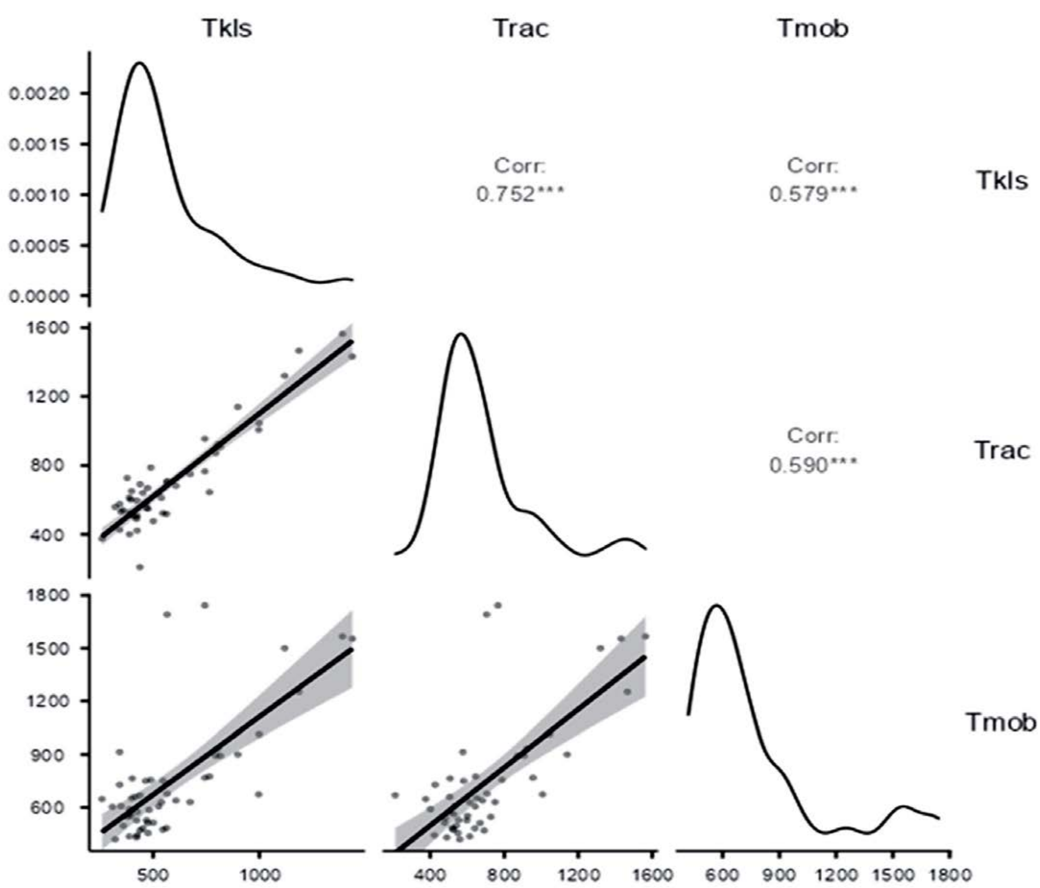

Figure 3: The distribution of the data using results of Spearman's rho.

Table 3: Paired sample T-test.

			Statistic	*p*	Mean difference	SE difference	Effect Size
*T*kls	*T*rac	Wilcoxon *W*	89.5	< 0.001	−121.45	16.0	−0.8478
*T*kls	*T*mob	Wilcoxon *W*	101.0	< 0.001	−130.00	33.0	−0.8477
*T*rac	*T*mob	Wilcoxon *W*	599.5	0.901	−2.50	36.0	−0.0212

($p < 0.001$, $W = 101.0$) cases. The effect size for these analyses was found to exceed the Cohen's convention as large ($d = 0.848$).

The Wilcoxon test shows that using a smartphone and computer while calculating tasks produces similar results while using the calculator produces different results.

The Shapiro-Wilk statistic was calculated to test the assumption of normality for the paired samples t-test. The result of the Shapiro-Wilk test showed that the assumption of normality was violated in the *T*kls – *T*mob ($W = 0.786$, $p < 0.001$) cases and *T*rac – *T*mob ($W = 0.795$, $p < 0.001$) while it was not violated for *T*kls – *T*rac ($W = 0.976$, $p = 0.410$).

calculated with an electronic calculator, which has been mostly abandoned in private life because the alternative is always the hand as an application of smart devices that become "Swiss Army knives" of digital technologies.[25] Based on the results presented in the previous chapter, we can conclude that students in both cohorts, 2019 and 2022, took more time to solve the tasks when they calculated them using a desktop computer calculator and basic calculator apps on their smartphones. While the small sample limits the extent on which the findings can be generalized, we nevertheless can conclude that for some students, using the smartphone calculator takes much more time also if compared to the desktop computer calculator. It has

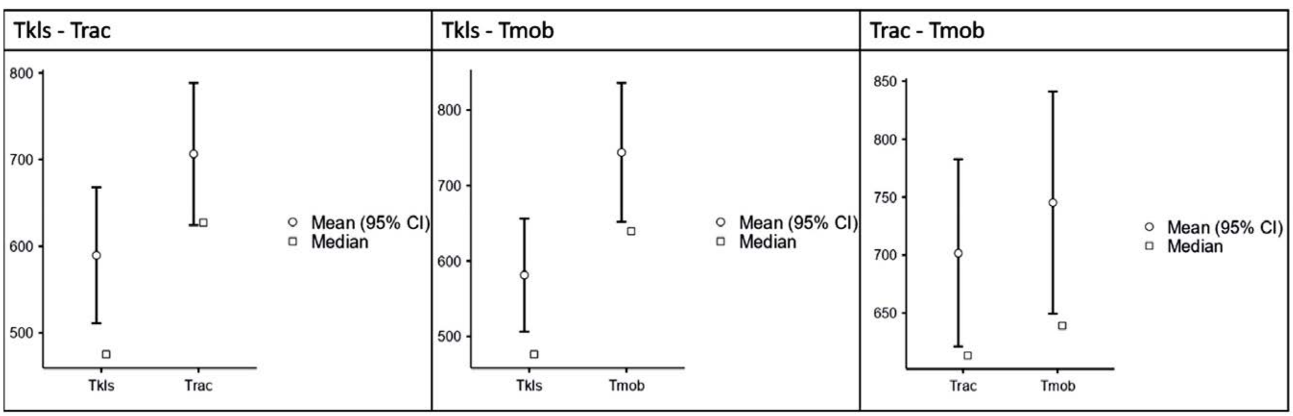

Figure 4: The distribution of the pairs of the data.

In Figure 4 we present the data distribution with the 95% confidence interval, which shows that there are no important differences between the time needed for solving tasks when calculated with a desktop computer calculator and smartphone calculator, but there are important differences when comparing the time needed for solving chemistry tasks with an electronic and a desktop computer calculator or with an electronic and a smartphone calculator. From each plot it is obvious on which approach the students used to solve the task faster.

been reported in earlier research, that the time spent on task is known to corelate with the results, with unsuccessful students turning to a quick solution while the successful students spending more time while solving the task.[26] However, due to a different experiment design, the conclusions are only partially comparable with the present study.

4. Discussion

Calculating chemistry tasks is part of students' daily routine in chemistry classes or in the laboratory when preparing solutions or dilutions. The results of our study indicate that chemistry tasks can be solved most quickly when

From our results we can draw some conclusions about the factors that may influence the choice of technology in a classroom. The technology teachers choose to use in the classroom, usually depends on the educational goals they want to achieve and the availability of those technologies. Computers, and especially in the last decade smartphones, are commonly used as educational tools in learning environments. Their integration is believed to have positive effects on student learning expectations and outcomes.[27] The use of computers in chemistry classrooms is common when working with computer-assisted teaching and learning (CATL) methods.These have been around for years and are mainly used teach students the basic concepts or principles of a dynamic chemical process.[28,29] Since all desktop stationary and mobile computers have built-in calculators, their use can be approved. However, in line with our findings, computers should be used primarily for explaining and illustrating concepts rather than for calculating the above written tasks. In working practice, the desktop computer calculator is mostly used in chemistry for mathematical calculations such as addition, multiplication, subtraction or division. Therefore, the use of the PC-integrated calculator for the calculation of basic chemistry tasks, although justified, is not an optimal solution.

Since chemistry calculation tasks are usually solved in classrooms or laboratories where students do not have their own laptops or PC-s and the smartphones, because of their omnipresence (if allowed in a classroom), are the next choice of the teachers to be inline with 'digital natives'.[30]

Over the past decade years smartphones have become more and more prevalent in the school day. It has been suggested that they can be a useful tool in chemistry to learn the naming of organic chemical compounds,[31] to use them in analytical chemistry for optical and electrochemical detection and chemometric applications,[32] for quantifying gold-nanoparticle concentrations,[33] for pH determination,[34] many students need the smartphone camera to make videos of demonstrations, to copy complex diagrams from the blackboard[35] etc. In addition, chemistry apps such as Chemdoodle, Periodic Table, Chemistry Helper, Reaction Flash, Learn IUPAC Nomenclature, Chemical Solution Calculator and many others whose target audience is students, chemistry professionals, and teachers, provide them with powerful and compact tools to solve problems conveniently and free themselves from traditional media, heavy books, and bulky computers.[36] Yet, in our study, they were found to be the least effective tool for computation compared to desktop computers and even traditional electronic calculators.

In summary the use of traditional calculators should be encouraged because of their efficiency, not because of arguments against the use of smartphones in a classroom or the lack of stationary or mobile computers in a classroom. Reasoning that in faculties or in a school the use of smartphones should be allowed during the learning process (searching for information, calculating tasks, recording processes, etc.) but should be prohibited when writing exams because of potential cheating is plausible, but efficiency in time management should be a priority. Nevertheless, unintentionally because of this system students have to get used to using electronic calculators to solve the basic chemistry tasks especially those similar to the given ones, which is the least time-consuming approach.

To our knowledge this study is the first to provide information on the time comparison for the fastest way to calculate basic chemistry tasks similar to the one presented here, using three different approaches. An important limitation of the study was that students self-measured their time rather than using more objective measures. For future studies, it is suggested that an objective supervisor be involved in the measurement.

5. Conclusions

Problem-solving ability has been reported to be one of the most important skills and is predicted to be even more important in the future and thus needs to be emphasized during teachers' pre-service education. One of the basic skills for future chemistry teachers is to perform basic chemical calculation, using digital technologies. Three different approaches, using either electronic calculator, smartphone calculator, or desktop computer, were considered in the study. Although our sample size does not allow for generalization, we can draw conclusions about the fastest way to solve chemistry tasks based on the results presented above.

From our everyday experience, we can conclude that electronic calculators are mainly used for arithmetic in chemistry classes, while smartphones and computers are intended for broader use. Therefore, it is not surprising that the presented results of 2019 and 2022 show that the chemistry tasks are on average solved most quickly with the electronic calculator. Unexpectedly, the fastest particular way to obtain the result was with the desktop computer calculator. The research showed that students who took more time to solve a chemistry task using one approach also took more time to solve them using other two approaches, suggesting that students' general problem-solving ability and chemical calculation skills are more important than the choice of the particular digital technology approach.

The results may act as a suggestion to future chemistry teachers' training, showing the need to identify the task and choose the most efficient way to solve it and include those skills later in their classroom practise. The possibilities to further improve future chemistry teachers' skills in chemical calculation, as well as performing correlations between time spent on the calculation and the validity of results, depending on the three calculation approaches, should be the subject of future research.

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Ethics statement

All participants voluntarily participated in the study. All data were anonymized to ensure participant privacy.

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Povzetek

Učinkovitost porabe časa je ključni dejavnik pri računanju kemijskih nalog, ki vpliva tako na osebno kot poklicno področje. Študija je namenjena iskanju najhitrejše metode za reševanje kemijskih računskih nalog. V raziskavi smo primerjali čas, ki ga študentje porabijo, ko pri reševanju računske naloge uporabijo tri različne načine: računanje z običajnim kalkulatorjem, računanje z aplikacijo kalkulator na pametnem telefonu in računanje s kalkulatorjem namiznega računalnika. V raziskavo smo vključili 52 slovenskih študentov, predmetnih učiteljev, ki so bili aktivno vključeni v programe kemije in sorodnih naravoslovnih programov v študijskih letih 2019 in 2022. Rezultati iz leta 2019 kažejo, da študentje rešijo kemijske naloge najhitreje z uporabo običajnega kalkulatorja in porabijo največ časa za izračun nalog ob uporabi aplikacije kalkulatorja na pametnih telefonih (Δ_{mean} = 133 s; Δ_{SD} = 5 s; Δ_{min} = 97 s; Δ_{max} = 131 s). Še večja razlika je opažena v podatkih iz študijskega leta 2022 ($\Delta_{povprečje}$ = 189 s; Δ_{SD} = 129 s; Δ_{min} = 170 s; Δ_{max} = 625 s). Če povzamemo: čeprav so pametni telefoni večopravilne naprave, ki nadomeščajo tradicionalne enonamenske naprave, so bile naloge hitreje rešene z običajnimi kalkulatorji.