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A Chemistry and Society Book with Experiments and Discussion of Climate Change

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Abstract: In a chemistry course for students not majoring in science, there is more to learn than some memorized facts: the student can find, in most non-major chemistry texts, the definition of atomic number, something about chemical bonding, and names of some classes of chemical compounds. Where facts come from and how accurately they are known are often missing. A book is now available in which a number of experiments are included. The first two "experiments" can be done in class; they help the student to understand what is meant by experimental error, accuracy, and precision. The remaining experiments are real, and require a laboratory. In courses lacking labs, students can be given the results, as done by technicians. This was done when the course was most recently taught. Three repeats of measurements allowed an error estimate, to be included in a student's pseudo-lab report. Most lab reports indicated the students understood the material. The text included a qualitative introduction to thermodynamics and black-body radiation, to present some of the science behind climate change. pH is introduced with application to ocean acidification. A Chemistry and Society book should apply the science to the most pressing societal problem with a scientific basis. Also, the book starts with a much more considered introduction to what is usually passed over as "scientific method". There is a fairly extended discussion of the distinction between hypothesis and well-established theory. There is a chapter on the history and philosophy of science, not going deeply into either, but setting out much more than is found in many books. The book is Chemistry and Society (M. E Green, 2018, Linus Publishers). Based on the final exam over 2/3 of the students understood the material. Overall, this did as well as standard texts, when used for the same course.

Keywords: Public implications of science, Scientific proof, Climate change, Student experiments, Error analysis

Introduction

A science and society book for non-science majors has more than one purpose. It must introduce the student to some of the facts of one science or another, or sometimes some combination. Most textbooks for such courses do this, often quite well. There is a variety of books for such a course in chemistry; here we cite a couple of examples, but this list is not at all comprehensive(Cooper, 2020; Jordan, 2017). On-line separate topics that

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allow a faculty member to prepare an individual curriculum also exist, e.g., this site from Lumen Learning("Chemistry for non-Majors," 2021). Timberlake and Timberlake have a book that is in its sixth edition (Timberlake & Timberlake, 2016) Each book has its own emphasis. For example, the book by Jordan just cited emphasizes biochemistry. There is a successful multi-author series with the American Chemical Society listed as author, now in its tenth edition; this is accompanied by an optional lab manual, one of very few that has that even as an option. That book includes chapters on climate change and other public policy issues.

It is worth considering why we require non-science major students to take such a course. It has been suggested by Baum (Baum, 2004) that it is because the non-majors will play a key role in setting public policy, and therefore need to know enough science to apply it to public policy. In essence, this is the same point of view we take here. The specific facts (atomic weights, ionic vs covalent bonding…) will do little to affect the future course of the students understanding of life. If taught merely as specific facts, they will be learned for the final exam, and forgotten. The fact that such facts exist is itself useful, and will be retained; the existence of such facts, possibly together with understanding that these facts have been established by rigorous methods, and can be accepted as true, is important. This is not trivial, given the attacks on science we are experiencing. However, if we give the students no reason to understand how the facts are established, then the student leaves by the same door wherein they came. Furthermore, the use of science in understanding certain problems in society is, to scientists, obviously essential, but to much of the population, not appropriate at all. Students, at least, should understand the fundamental reasons that science is a reliable guide to policy, as well as the limits of science, because of error limits on measurements, and the necessity of building upon what has gone before. The course must enable the student to understand why the facts obtained by the use of scientific methods and measurements are reliable, and the conclusions that can be drawn from them can be relied upon. If, in addition, the course applies to the leading problem of the day for which technical content is central, in this case climate change, it has further salience, and for many students would be reason in itself to pay serious attention to the course. If students take in the material with some degree of seriousness, they will be able to participate that much more knowledgeably in the public discourse on the subject.

This Book (Green, 2019)

We take a viewpoint that non-major students need to know enough science to be able to appreciate scientific arguments. This includes understanding where scientific knowledge comes from, what the limits on this knowledge are, and why we can be confident that when properly acquired, this knowledge is reliable. If the student gets the sense of how data are acquired, and what is meant by accuracy, this makes it possible to not only understand but see the reason for accepting scientific results. Error limits mean the results are not exact, but they also mean that the results are reliable with these limits. The student will not come away as a scientist, but should come away with an appreciation of the reasons for doing science, and the importance of using the results of scientific work in setting public policy. Therefore, we will here go through parts of the book, sufficient to gain an appreciation of what the book does, and what the student should come away with. For this reason, we integrate experiments with text, so that the student gets the sense of how at least a little of the information being discussed in the chapter can be acquired. Some specific topics are covered that are necessary for the overall understanding of the discussion of climate change, but might not otherwise be covered in a book at this level. We include thermodynamics. Other books discuss heat, sometimes entropy, but it is relatively unusual for such a course to discuss the laws of thermodynamics; it is necessary here for understanding much of the science behind energy generation, with application to energy storage. In general, the book was written with a more physical point of view than most chemistry books for non-majors. It covers the material needed to understand the main points that it is intended for the student to understand; the student, by the end of the course, should be able to contribute to the public discussion of science, and of its application to climate change. The price for this is that the student will have seen less of the standard material than is found in most texts. The book is designed for a one semester course and is set up to be covered in the order presented; the later chapters depend on material covered in the earlier chapters.

The book begins with a discussion of “scientific method” that is more extensive, and less simple, than that usually given. The difference between hypothesis, a guess, and theory, generally well established, with much evidence, is considered. There is a limited discussion of the philosophy of science. Topics discussed include Popper’s ideas on approaching a proof by failure to disconfirm a hypothesis by experimental tests: testing a hypothesis by experiment is necessary, as well as understanding that one cannot generally prove something right, but one can prove it wrong; if after enough attempts to prove it wrong have failed, one must begin to believe that it is not wrong. There is a more extended discussion of what experiments do, and how they are analyzed, and relate to a testable hypothesis. This has a further implication: one cannot take an experimental result as infinitely precise; there is always a limit to the accuracy of measurements. Until one knows how accurate a measurement is, one cannot know whether the result can be trusted to drive a policy.

The experiments have two roles: they show the students how it is possible to know something: one must measure it. There are enough experiments to make this point clear. In addition, whether the students do the experiments themselves or not, they do the data analysis, including experimental error, a topic often omitted in presenting “facts” in a course for non-majors; this includes a fairly formal error analysis for each experiment. A couple of the experiments may be too difficult for the students, or they may require more time than is available in the typical student lab period; in these cases, the students must be given data. However, there are enough real experiments that students could actually do their own measurements, if the course schedule includes labs; if not, they can be given the results of the experiment, as done by technicians; the students must still do an error analysis based on the scatter of these measurements. The last experiment, involving black-body radiation, is also somewhat difficult without equipment not always found in a first-year lab, and simulated data can be used. However, this topic cannot be avoided in a discussion of the science behind climate change. On the other hand, experiments involving pH are entirely feasible, and could be done by the students themselves. In the text, the topic is applied to the falling pH of the oceans, which is one of the effects of increasing atmospheric CO_2 concentration. The discussion of acids and bases includes the $H_2O + CO_2$ equilibria, with an explanation of how this affects ocean pH. One problem that showed up with some students was that they had lost even their junior high school arithmetic, so there is a brief (re)introduction to logarithms and exponents. Hopefully most students could skip this, but either way it was possible to discuss pH after this.

The experiments were mostly fairly simple; the students would be in the lab for probably the only time in their lives, and there is no way they could be expected to be highly precise. Neither were the measurements always very interesting scientifically. One simply required the students to prepare a solution of known concentration. That experiment is inserted here as a sample:

Sample Experiment

Experiment 4A: Preparing Solutions of Known Molarity

Instruments and Materials

One 250 ml plastic graduated cylinder, one stirrer and one stir bar, one stemless funnel, one deionized water bottle, one 9 cm glass pipet, one pipet bulb, one spatula, an electronic balance, deionized water, paper towels, and several packs of sugar. Refer to Figure E4A-1 for details.

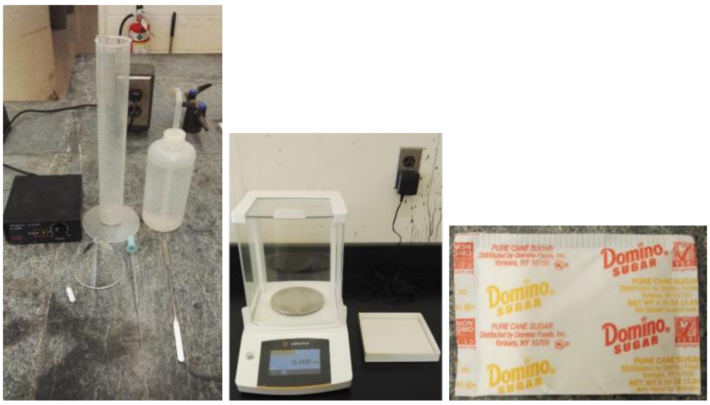

Figure 1. Instrument and Materials used

Experimental Procedure

1. *Equipment Setup*

Place the 250 ml cylinder on top of the stirrer, put a stirring bar inside the cylinder, add deionized water to the cylinder, and use the 9 cm glass pipet to break the air bubbles inside the cylinder; then continue to add water up to the 230 ml mark of the cylinder; record this under the "cylinder mark before sugar added" column in Table E4A-1. Wipe the water on the cylinder wall above the 230 ml mark with a paper towel. Place a stemless funnel on top of the cylinder.

2. *Measuring the volume expansion of sugar*

   a. Weigh one sugar bag to the nearest milligram (0.001 g); record the mass in the "mass of sugar packet" column in Table E4A-1.

   b. Turn on the stirrer, carefully open the sugar packet (keep the torn paper bag), and slowly transfer the sugar into the cylinder via the stemless funnel. Lightly tap the funnel and the cylinder wall to let the sugar all transfer inside the water. Stir for several minutes to let the sugar dissolve. Turn off the stirrer. Read the water level in the cylinder when the water has stopped moving, and record it under the column of "cylinder mark after sugar added" in Table E4A-1. Weigh the torn paper bag, record its mass in the "mass of paper bag of the sugar packet". ***Show your data to your instructor before you proceed to the next step.***

   c. Weigh another sugar bag to the nearest milligram, repeat **step 1) and 2)**. Continue to add two more sugar bags following the same procedure into the cylinder to finish **Trial One** test.

   d. Dump the sugar solution into the sink, **keep the stirring bar**, and rinse the cylinder several times to clean it. Repeat **step 1) to step 3)** to run another two tests: Trial Two and Trial Three. Record the results in Table E4-2 and Table E4-3 respectively. Note on Tables: Add lines for trials as needed—the number of blank lines here is not sufficient.

3. *Cleanup*

Dump the sugar solution to the sink, rinse the cylinder, clean your bench, and put everything back as it was when you entered the lab.

Data Entry: Sample Tables for three repetitions of the measurement

Table 1. Trial One Experimental Result

Trial One	Mass of sugar packet (g)	Mass of the paper bag of the sugar packet (g)	Sugar Added (g)	Cylinder mark before sugar added (mL)	Cylinder mark after sugar added (mL)	Volume increase (mL)
1						
2						

Table 2. Trial Two Experimental Result

Trial Two	Mass of sugar packet (g)	Mass of the paper bag of the sugar packet (g)	Sugar Added (g)	Cylinder mark before sugar added (mL)	Cylinder mark after sugar added (mL)	Volume increase (mL)
1						
2						

Table 3. Trial Three Experimental Result

Trial Three	Mass of sugar packet (g)	Mass of the paper bag of the sugar packet (g)	Sugar Added (g)	Cylinder mark before sugar added (mL)	Cylinder mark after sugar added (mL)	Volume increase (mL)
1						
2						

This is the form given to the students, if the students are to do the experiments themselves. If the students do not have a lab period, they are given the results, which are in the instructor's manual; here are the results for this experiment, as given in the instructor's manual; the instructor in this case will give the results to the student. With these results, the students are expected to write a lab report. When the course was taught at City College of New York, this was done.

Table 4. Trial One Experimental Result

Trial One	Mass of sugar packet (g)	Mass of the paper bag of the sugar packet (g)	Sugar Added (g)	Cylinder mark before sugar added (ml)	Cylinder mark after sugar added (ml)	Volume increase (ml)
1	2.970	0.173	2.757	230.0	232.0	2
2	2.958	0.172	2.786	232.0	234.0	2
3	2.983	0.176	2.807	234.0	236.0	2
4	2.987	0.173	2.814	236.0	238.0	2

Table 5. Trial Two Experimental Result

Trial Two	Mass of sugar packet (g)	Mass of the paper bag of the sugar packet (g)	Sugar Added (g)	Cylinder mark before sugar added (ml)	Cylinder mark after sugar added (ml)	Volume increase (ml)
1	3.051	0.168	2.883	230.0	232.0	2
2	3.027	0.172	2.855	232.0	234.0	2
3	2.954	0.174	2.780	234.0	236.0	2
4	3.005	0.170	2.835	236.0	238.0	2

Table 6. Trial Two Experimental Result

Trial Three	Mass of sugar packet (g)	Mass of the paper bag of the sugar packet (g)	Sugar Added (g)	Cylinder mark before sugar added (ml)	Cylinder mark after sugar added (ml)	Volume increase (ml)
1	3.040	0.167	2.873	230.0	232.0	2
2	3.042	0.176	2.866	232.0	234.0	2
3	2.954	0.173	2.781	234.0	236.0	2
4	2.926	0.171	2.755	236.0	238.0	2

There is enough scatter in the data as given (this is real data: the experiment was actually done by lab technicians) for the students to do an error analysis. They are also expected to answer questions at the end of the lab report.

Error analysis: from the scatter in the repeat measurements, estimate how accurately the solutions have been prepared.

Answer the following questions:
1. What is the Molar mass of table sugar? ___________________________
2. How many moles of sugar are in one packet of sugar, assuming the weight on the label is correct? How many moles, based on your weighing of the contents of the packet? ___________
3. How many moles per liter are in each sugar solution? _______________
4. How large is the scatter in the repeat measurements? Can you estimate the precision of the volume measurement? The accuracy (here, beware of bubbles)? _______________________

This experiment was accompanied by text introducing molarity, and then pH. There was an experiment on pH as Thwell, in which $CaCO_3$ is dissolved. Originally it was intended to use CO_2 in water to dissolve calcium carbonate. The experimental procedure is provided in detail to show what the student is expected to do, and the questions show what the student is expected to understand.

Note: Dropping the pH with CO_2 in water produced a pH drop insufficient to dissolve $CaCO_3$ during class time, so a strong acid had to be used to do that experiment in the time available.

Discussion to This Point

The introductory material is suitable for the first week of the course, concerning definitions of theory and hypothesis, references to Karl Popper and Thomas Kuhn, and other material devoted to discussion of what science is about, and how it proceeds. We then proceed go on to the basics of chemistry, which are must be in any book on the subject. These include atomic weights, the nucleus and electrons, elementary stoichiometry, solution concentrations, and chemical bonding. What is not always present is a fairly extended discussion of equilibrium and rates, leading to a need for a basic understanding of thermodynamics. The main section of the book, through experiment 9, and the Summary on Chemistry, has relatively little direct relation to climate change, although the lowering of pH of the ocean is discussed with pH. The inclusion of experiments illustrates several of the main concepts e.g., error analysis). Texts that have no experiments, hence no error analysis or discussion of how we know what we know, and to what accuracy, fail to teach a central aspect of what science means. By including experiments, we allow consideration of the kind of work needed to establish scientific facts. Thus, by about 2/3 of the way through the book, the student should have learned the kind of effort required to obtain facts, and have come to understand the necessity of having a good estimate of how well the fact is known. In addition, the student should have learned fundamental chemical concepts, including bonding, chemical reactions, both as to equilibrium and kinetics, and the other topics listed earlier. This accomplished, it is possible, and necessary, to apply what has been learned to climate change.

Rates of Reaction and Chemical Equilibrium Followed by Thermodynamics

Rates and chemical equilibrium are presented before the introduction to the Laws of Thermodynamics. We start with the idea that a reaction must overcome a barrier, and use the standard simple diagram:

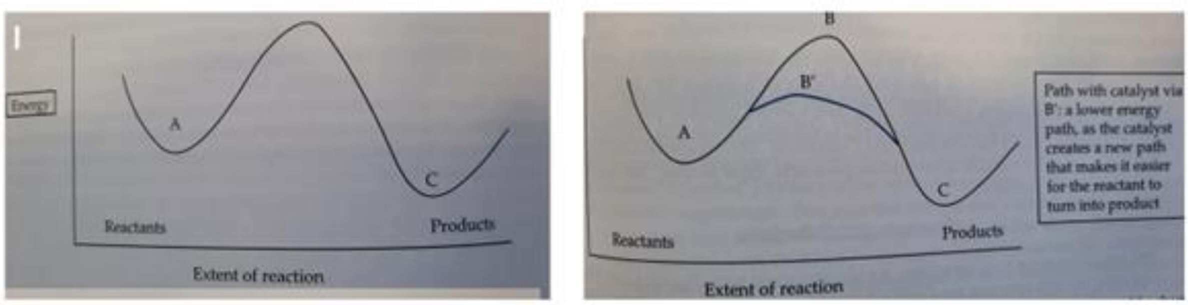

Figure 2. These figures show the energy barrier for a reaction without (left) and with (right) a catalyst, shown to lower the barrier to reaction, speeding it up. In the book, these figures are only 3 pages apart. The idea of an energy barrier is introduced early in the chapter on rates and equilibrium.

Once the idea of rates is understood, equilibrium follows, and the relation of equilibrium to the ratio of rates is next. Again, simple figures illustrate the point. There is no math used.

To illustrate the idea of equilibrium, and the ratio of the rate of a forward reaction to the reverse reaction, Figure 3 was used:

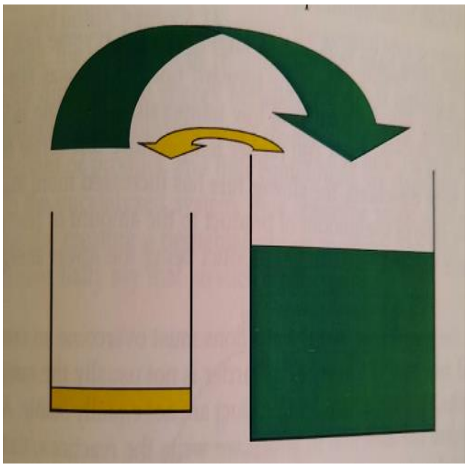

Figure 3. (This caption is copied directly from the book, and illustrates what the student was given, so as to be able to understand the relation between the ratio of rates and chemical equilibrium)

Forward and reverse reactions at equilibrium. In this example the reaction from left to right is fast (the big arrow), from right to left slow (small arrow) As a consequence, the amount on the right (the product, shown in green) is large compared to the amount left (reactant, shown in yellow) One can think of the arrows as a sort of pipe, with the amount that can go through determined by the size of the pipe. On the other hand, the amount of material in the product bin is larger in exactly the same ratio as the amount the pipes carry in the two directions. As a consequence of the ratio of amount equaling the inverse ratio of the rates, the amount passing through the pipes, forward and reverse, is the same per unit time, and amounts of the substances, yellow and green, do not change with time. The system remains at equilibrium.

With a little further explanation, the students understand that the ratio of the rates is the inverse of the ratio of the amount of each substance at equilibrium; it has to be made clear that the rates apply to the entire amount, so that the "pipe:" analogy does require a little modification. However, the point does become clear.

After the diagram in Figure 2, this understanding can be extended to the effect of temperature; higher temperature makes both rates larger, as the barrier in the figure remains the same, but the energy available to climb the barrier becomes larger, so both "pipes" (rates) become larger, but the smaller one increases more, relative to the larger one, so that the equilibrium shifts in favor of the higher energy substance, in this example the reactant. A figure similar to Figure 3 makes the point graphically.

Two experiments (but counted as only one of the eleven; only one can actually be done in lab) go with this chapter. The first experiment (in principle only—not to be done in lab), is the reduction of $Cu(H_2O)_4^{2+}$ by metallic tin. This takes too long to actually do, but by including the description not only of a rate measurement, but temperature as well, helps the student to understand the chapter. The questions that the student must answer (with help from the instructor, since the data are not actually available) are as follows:

1) What equilibrium was studied in this experiment?

2) Why does temperature change affect equilibrium in a chemical reaction? (Remember Fig. 7-1) (*this is Fig. 2 in this paper)*
3) How can you tell when chemical equilibrium has been reached in a reaction? Caution: Your answer will be valid for this reaction. In some cases, there are more complications.
4) Why do we expect the initial rate to have a regular pattern, but expect the equilibrium and also the later parts of the rate curve to be more complicated? *(Note: This is a tricky question, and probably should have been omitted)*
5) Is there an upper limit on the concentration that it is prauch a limit?ctical to use in this experiment. What determines such a limit? Is there a way to work around the limit? (Hint: the answer to this last question is not so obvious.)

This gives a sense of what the student is expected to understand; the questions are to some extent open ended, and allow the student to show his or her level of understanding of the principals involved.

This done, a more practical experiment, which the student can actually do in lab, is provided. The dye FD&C Red #3 is oxidized with 6% NaOCl (household bleach, essentially). The loss of color as a function of time is measured with a spectrophotometer. Two concentrations of dye are used, and the rates compared; a log(absorption) vs time curve gives the rates (by this time, those students who needed a review of logs have had the review). The questions that go with this experiment are more directly related to the experiment itself, and include questions as to the reason the late readings are less likely to be accurate.

Taken together, this chapter illustrates the approach to getting the students to understand both the principles underlying chemical processes (Figure 2 is valuable here), some of the consequences of these principles, and then, with the aid of an experiment, helps the student to see how they apply to a real system. It is expected that the student will be able to see how the same ideas apply in other cases.

Thermodynamics: In the next chapter, we go through the Laws of Thermodynamics. The fundamental principle of the First Law and the Second Law is not hard to illustrate. For the Second Law, for instance, we use the classic example of the ship that cannot move by using the energy of the sea water, spitting out ice cubes at lower energy. This does not violate the First Law, and is a clear example of the limitations set by the Second Law. We also note that these two Laws are stability conditions for any well-run universe. It would be inconvenient to have things pop in or out of existence, forbidden by the First Law, or to have all the air in a room go to one side, forbidden by the Second Law. It is not difficult for students to get the point.

Once we have this much, we introduce heat, work ΔH, ΔS, and then ΔG; we can then reinterpret Fig 2 in terms of ΔG. There are two experiments, one illustrating exothermic and endothermic reactions (dissolving KNO_3 in water, endothermic, and one dissolving $CaCl_2$, exothermic). There is a second experiment using osmotic pressure to illustrate ΔG as the driving force. While osmotic pressure is an odd topic in this level course, it is a clean illustration of how ΔG determines the result of a chemical (sort of) process. The fact that no chemical reaction is involved simplifies the interpretation for the students.

Of course, an experiment must go with this, and we use two: one is freezing point depression, which is simple and practical. The salt used for the solution is NaCl, although others would do; NaCl is easily available and cheap. The other experiment is less practical, and may not be done in class; however, it does allow the student, by considering what drives osmosis, to understand how ΔG drives the process. Students can be given data, or pseudo data, to analyze.

For the freezing point experiment, the questions the students must answer at the end of the lab report include:

1) Can you see a way to make the freezing point determination more accurate with the same thermometer? If not, why not? [Note: the thermometer, according to the instructions, should be accurate to 0.1ºC.]
2) Can you think of a physical reason for the existence of a latent heat of fusion? Would you expect that there would be a latent heat of vaporization when water boils? Would this be larger or smaller than the latent heat of fusion? (Hint: think about the differences in the molecular arrangement between the solid (all molecules in contact, and well ordered, liquid, all molecules in contact, not well ordered, and vapor, molecules far apart, no order)
3) Would a solution of sugar in water have a lower or higher *boiling point* than pure water Explain. (Hint: Go back to the explanation of freezing point depression. Then consider that the vapor phase with which the water must be in equilibrium in order to boil has a *higher* free energy than that of the liquid water, while ice has a *lower* free energy. We had to withdraw extra free energy from the liquid to get it to freeze; we have to add free energy to make the liquid be in equilibrium with vapor. What is the consequence?
4) Which of these would have the lowest freezing point: a) 1 M sugar solution; b) 0.7 M NaCl solution c) 0.5 M $CaCl_2$, which should produce 3 ions per $CaCl_2$ d) a solution of 400g of a non-ionizing substance, with a molecular weight of 1000 g/mole, in one liter of water.
5) Of the solutions in question 4, which would have the largest, and which smallest, osmotic pressure? Why? Is the question really redundant after question 4?
6) We said that the freezing point depression should be 3.72ºC/M. (that is, 3.72ºC per molar concentration) Can you detect the difference between your measurement and 3.72ºC/M, when you take into account the experimental error?

These questions suggest at what level the students were expected to understand the driving force for physical processes and the role of free energy. It was still necessary to use "Hints" to pull them across some barriers that they would not otherwise have been able to cross in answering these questions. However, in a qualitative way, they are expected to have a reasonably sophisticated understanding of what drives physical processes. They should also be able to put the previous, rates and equilibrium, chapter together with this newer set of ideas. The instructor may have to help the student realize the connection, although the book does try to do this. Since this was preceded by a chapter on how free energy drives chemical reactions, and the freezing point depression/osmotic pressure physical processes are presented as directly analogous to chemical reactions, the students are expected to come away with a physical understanding of how thermodynamics controls processes in the real world. Along the way, they must acquire some basic physical understanding, for example, of why the free energy of water in pure water is higher than it is in a solution, or why water in the vapor phase has higher free energy than in the liquid.

If there were only text, and no experiment, it would be much more difficult to make the connection between free energy, the First and Second Laws, and real processes like chemical reactions or freezing point depression. Along the way, we introduce the standard thermodynamic quantities of heat, work, energy, enthalpy, and entropy. All this is done using no math beyond elementary arithmetic, and as little of that as possible.

With the concept of free energy, and equilibrium and rates, the students can understand how black body radiation from the sun and from the earth leads to something like a steady state and fairly constant energy balance. We proceed to that topic.

Summary of The Remainder of The Book, With the Applications to Climate Change

1: There is one other topic that must be covered before enough of the background can be understood by the student to proceed to climate change: light and radiation. This is rarely taught in a chemistry course at this level, not because it is not an appropriate topic in chemistry, but because it is not all that easy to explain, and partly because it seems to be a specialized topic. It is often enough left to advanced courses, omitted even in science major chemistry courses. In reality, it is not less relevant than teaching more reactions, or more examples of plastics, which is a specialized topic itself. In fact, light plays a critical role not only in providing energy for some chemical reactions (including some polymerization reactions that lead to plastics), but also in the energy balance of the earth. It is in the latter context that we discuss light, and black body radiation in particular. For this we have to start with introducing electromagnetic waves, but even before that, the idea of waves. It is then possible to introduce wavelength and frequency, and the idea of a spectrum. With this, it becomes possible to introduce black body radiation; thermodynamic equilibrium having already been discussed, the idea that this radiation is in thermal equilibrium is natural.

Ocean acidification has been discussed with the introduction to pH. Other examples of the role of lower pH on $CaCO_3$ include the erosion of monuments, including the Taj Mahal, which is largely made of marble. However, the main discussion concerns the effect on sea creatures that form $CaCO_3$ shells. This begins to suggest how the human production of CO_2 affects the environment, even before we come to the effects on climate.

The emphasis on climate change requires introducing discussion of alternate energy sources. The earlier introduction of thermodynamics, in addition to rates and equilibrium of chemical reactions, makes this somewhat easier. The discussion of spectra is somewhat detailed, as it is necessary for the student to understand how there is a difference between what the earth absorbs and what it reradiates, which in turn requires the extended discussion of black body radiation. In addition, the added contribution of CH_4 to light absorption in the atmosphere and thus atmospheric heating can only be understood with a discussion of absorption spectra. Overall, therefore, there is an appreciable section devoted to light, black body radiation, light absorption, and their measurement. Thus, the students are introduced to spectrometers. This being a course with experiments, there are two out of eleven experiments devoted to light absorption and spectroscopy. The eleventh experiment is difficult, and may be omitted when the course is taught, but is well worth discussing. The problem is that there no good way of producing black body radiation in a manner that fits an ordinary lab spectrometer, unless a high temperature source is available, and some sort of light pipe (optical fiber) can be obtained. However, the experiment may be modified or adapted, and in any case, it is not critical that it is actually done. The book has the standard graphs illustrating the "hockey stick" increase in global temperature, as well as the Keeling curve showing the rise in CO_2 with time. In essence it is a standard discussion, but this time the students have the background to understand where the data is coming from, and enough experience to understand how the data must be taken seriously. No extended discussion of the effects of climate change is included, as this is beyond the scope of the chemistry text. It would be good to add a second semester to this course, devoted to earth science, which could include all the effects to be expected from climate change. However, this seemed too great a diversion for a book that needed the entire semester to teach the rudiments of chemistry.

2. Finally there is a chapter on nuclear energy. An earlier version of the book was used in 2011 when the Fukushima meltdown was occurring, so it became necessary to include that material in that class, and the notes for that class have been expanded into a chapter here. No experiment goes with this chapter, but the basic ideas of radioactivity, half-life, chain reaction, and the structure and function of a boiling water reactor, are covered. The discussion is agnostic as to whether the use of nuclear power is a good thing; the reactor does not produce CO_2, but disposal of nuclear waste is still an unsolved problem. It was not originally intended to include this chapter, but it is actually useful; students know at least a little about another public problem with a major technical component, and they have the background at this point to understand it.

Experiments

The book has 11 experiments, some with alternates, some with subsections, that are designed to illustrate many of the main concepts that constitute the text.

The first two experiments can be done in class. These are intended for teaching the ideas of estimating errors and of testing a hypothesis. The first experiment consists of comparing two lines (they have to be shown as perpendicular to prevent judging by eye); the lines are measured with a coin (not so accurate) and then a ruler with a mm scale (smaller error). The error estimate as done is augmented by illustrating the effect of using the more accurate test instrument, the ruler.

The largest number of experiments covers the chemical concepts that make up the central portion of the book. While the book is intended to have the students understand how science is done, and the relation to a critical societal problem, nevertheless it would not be a course in chemistry without covering fundamental chemical ideas. These topics are reinforced by the experiments. Often when the topics are first covered in class, they seem opaque to many students. The experiments both serve as review and reinforcement, and make the concepts concrete with specific examples that make the student work out the calculations for a real example. The concepts are not only the usual (pH, for example) but also the relatively unusual topic of osmotic pressure; this is not a normal topic in such a course, but it does illustrate the concepts covered in the sections on thermodynamics. Once the student has the idea that a process, in this case, water transfer across a membrane, is driven by a free energy gradient, much of the rest of chemistry makes sense. In this course, in which the student is expected to understand what drives chemical change, such an experiment is necessary. Osmotic pressure, in which there is a simple physical application of the change in free energy, without chemical complications, serves this purpose.

The final two experiments are directly concerned with light absorption and black body radiation. These topics are necessary for the discussion of climate change. The last experiment is difficult, in that it requires measuring a black body source. It is difficult to get the light from such a source at a relevant temperature into a spectrophotometer of the sort found in most first-year classes. This experiment may be only discussed in class.

Overall, the experiments, as noted earlier, also introduce students to the use of a limited set of chemical instrumentation. This is missing from a course in which experiments are not included. Even if the students do not get to do the experiments in a real lab, they can still be shown the apparatus and understand how the measurement is made, as well as the accuracy of the instrument. Optionally the lecture can cover the range of available accuracy in instruments; for example, there could be a discussion of the accuracy of spectrophotometers. However, this is not essential, and is not explicitly supported by the text. There is some discussion of the accuracy of balances, however. The initial in class experiment also covers the topic of accuracy of "instrumentation" (there, pennies and rulers, not real instruments, but the same idea).

If the students get to do the experiments, they come away with a valuable sense of what chemistry is about, and in particular the way in which chemical knowledge is obtained. Even if the students only see a demonstration, and then do a lab report with data obtained by technicians, they have learned more than they would by memorizing facts that are presented as true because the book says so and the teacher says so. They will not discover new facts, but they will discover what it means to discover new facts.

Summary

The book is intended to teach the students (not exactly in the following order):

1) the rudiments of chemistry
2) the nature of measurement, with the meaning of error analysis; to the extent possible, some experience with chemical experiments
3) what it means to say that something is proven, or disproven, in science
4) certain topics not always found in textbooks of this type, especially in thermodynamics, and blackbody radiation
5) the application of these concepts to ocean acidification and to climate change; this is a major point and is required for the students to know how what they have learned applies to the present major public issue with technical content. This is where the students will have to use judgment as political actors, and the book is intended to provide a basis for students to make the necessary judgments.
6) finally, the rudiments of nuclear energy, as it is used now for commercial power generation

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Appendix

TABLE OF CONTENTS:

The Use of Estimates in Solving Chemical Problems

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Abstract: The use of approximations in solving problems in sciences can be vital for students. Order of magnitude estimation also helps with physical understanding of the quantities involved in a calculation. For example, in the first exam in a first-year class in chemistry the student must find the mass in grams of an atom; a couple of students will multiply by Avogadro's number instead of dividing; for atomic weight around 100, this gives the order of magnitude of the mass of the moon; the moon is big, atoms are small. If the student considered the physical meaning of the mass, this would not be a possible mistake. Another example: calculate the total energy, and potential energy, of a system, and from these find the kinetic energy. If the kinetic energy comes out negative, something is wrong; the student should realize this. One place a student is taught an approximation in first year chemistry is finding the ionization of a weak acid; ionization is approximated by taking the square root of the dissociation constant times concentration, which only works if the concentration is large compared to the dissociation constant. If the student applies the approximation thoughtlessly, this produces an error. The adequacy of any approximation for accurate use is another concept that must be taught. Part of the use of approximations includes attaching error estimates to answers (sometimes expressed as significant figures). There is a second, related, matter that needs to be taught with the estimates; units must match. A book, "The Use of Estimates in Solving Chemistry Problems" (Green and Garland, 1991, Saunders) went through the quantitative parts of first year chemistry, showing how to estimate answers for all sections. A few examples from more advanced material are included too, as this kind of error persists past the first year.

Keywords: Estimates, Order of magnitude, Problem solving, Physical meaning of values

Introduction

The introduction of calculators in place of slide rules has produced a number of great advantages, but one major disadvantage. When students used slide rules, the order of magnitude of the result had to be provided by the student, so totally ridiculous answers were relatively rare. Of course, they were not non-existent, but the fact that the order of magnitude was the responsibility of the user of the slide rule meant that doing a calculation required at least some consideration of what the numbers meant. There were still cases of occasional students who memorized a formula instead of understanding it, getting it wrong, and then putting down an answer that was incorrect; rarely was it totally ridiculous, however. The classic case is the student who, on the first exam in first

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year chemistry, when asked to find the mass in grams of an atom with atomic mass 100, multiplies by Avogadro's number instead of dividing, getting something of the order of magnitude of the mass of the moon. The moon is big; atoms are small. If the student had any sense of the physical meaning of the number, he or she would immediately recognize that the answer is ridiculous, and would correct it. Even if calculators give the order of magnitude, a student who is not thinking may leave the answer, because it is what the calculator said; the student is not thinking about what the order of magnitude should be. While I do not regret the replacement of slide rules by calculators, slide rules did force consideration of what the order of magnitude had to be. Having a sense of what is reasonable is a skill that has been recognized by well-known physicists, at least. Enrico Fermi famously proposed problems with very little data, the most famous of which asked simply "How many piano tuners are there in Chicago?". No data was given, but if you think through the problem you can get the right order of magnitude. It is still the case that estimating orders of magnitude is part of the education of most physics students, and physicists routinely estimate orders of magnitude. This is less common in chemistry instruction, but would be just as useful. In order to find the answers to chemistry problems, it is a good idea to start with understanding what the system properties are. Unfortunately, it is all too common for chemistry to be taught with a lot of memorization, including equations. When a student relies on memorizing equations, it is usually the last chemistry course that student will pass. More advanced courses cannot be passed by memorizing equations. If the student is accustomed to thinking through the physical meaning of the numbers in the problems, then that student will understand the work, and will be able to move forward. The use of estimates in chemistry problems is offered in this spirit. The essential point has been recognized, sometimes in regard to particular cases, sometimes more generally, but limited or specific applications. For example, Penn has pointed out the general issue(Penn, 2018). Ryan and Wink gave a general example (candies in a jar), general in the sense that it introduces the idea of approximation without being tied to a particular chemical example(Ryan & Wink, 2012). Matsumoto et al gave examples suitable for a high school class(Matsumoto, Tong, Lee, & Kam, 2009) Specific examples include one topic that is found in most first year chemistry texts, but which students may find confusing, namely, pK_a calculations(Flynn & Amellal, 2016). By the time one gets to physical chemistry, approximations are even more necessary, and specific examples have been offered by a number of authors(Gasyna & Light, 2002; Lombardo, 2000; Nassiff & Boyko, 1978; Olivieri, 1990; Soares da Costa Junior, Marques da Silva, & Moita Neto, 1999; Viossat & Ben-Aim, 1993; Wallner & Brandt, 1999).

The overall approach can be illustrated by the one example in which an estimate is normally used in first year chemistry. The student is taught to make an approximation in calculation of the degree of ionization of a weak acid. The general form for this calculation is

$$K_d = [H^+][A^-]/[HA] = [H^+][A^-]/([HA]_o - [A^-]) \qquad (1)$$

where K_d is the dissociation constant, $[A^-]$ (= $[H^+]$) is the concentration of the corresponding ion, [HA] is the concentration of the undissociated acid, and $[HA]_o$ the total concentration of the acid plus $[A^-]$, thus the known concentration that was added to make the solution. If $[H^+] = [A^-] << [HA]_o$ one can approximate this by discarding $[A^-]$ in the denominator, making $[H^+] \approx (K_d[HA]_o)^{1/2}$, simpler than solving the quadratic that would be necessary without the approximation. The trouble is that the approximation is valid only for cases in which $[HA]_o >> K_d$. This is rarely explained to the student, leading to inappropriate use when the latter condition is not fulfilled. Usually the dissociation of a weak acid is introduced in cases where the condition is fulfilled, and later, if a case arises in which the approximation is no longer valid, the student still uses the approximation, as he or she has not been taught to think about the meaning of the numbers. For that matter, the approximation may be good when it is only necessary to get the pH to ±0.3, but not, with the same $[HA_o]$ and K_d, if it is necessary to calculate the pH to ±0.03. The connection between approximation and the accuracy of the estimated result also needs to be taught. Obviously, there are many more examples, and we will consider some more in the main discussion. The two main points are that numbers have physical meaning in chemistry and physics, and approximations are only accurate to a certain extent and it is possible to estimate the accuracy. Students often miss these points. They must be taught.

This is not trivial even in professional literature, where there are approximations, often, but not always, in connection with constructing models. Sometimes these approximations are used under conditions in which they are so far from correct, because the assumptions on which they are based are not nearly fulfilled, as to constitute physical errors. For example, calculating Debye lengths in systems that are too small to have enough ions to form an ionic cloud produces nonsense. Small systems, such as found in biology, for example in sub-cellular compartments, are subject to large fluctuations, a point which may reasonably be ignored in a first-year class, but which must not be ignored in professional literature. The same is true for some inorganic systems at surfaces, which, having one small dimension, sometimes act like a small system. This is not the main point of this paper; nevertheless, when this type of error appears in professional literature, it suggests that this should have been taught in the undergraduate curriculum, at least in simplified form, perhaps not in the first-year course, but certainly no later than physical chemistry. In the first year it may be possible to introduce fluctuations in an Honors section.

There are on-line tutoring sites, mostly intended for generic use with textbooks. The author is not aware of any first-year textbooks that systematically use estimates across the curriculum, and generally point to the physical significance of quantities in problems. There are exceptions in specific chapters of some texts, but it is generally correct that the use of approximations is not used as much as it should be, nor as systematically. The online sites are a good representation of standard treatments of introductory chemistry problems.

It is not the case that there will never be a gross error in a calculation, and this not limited to students; it is the case that such an error should recognized and corrected. To do this, estimating the answer, at least as to order of magnitude, will allow these errors to be avoided, or else corrected. Green and Garland(Green & Garland, 1991) addressed this problem in a book by going through the quantitative parts of the first-year chemistry curriculum and showing, using examples, how to start on problems by estimating an answer, at least as to order of magnitude. The standard solution followed the estimate in each example in the book, often with some discussion of what the physical meaning of the answer suggests. The usefulness of the estimate is somewhat variable, in that some answers allow simply an order of magnitude estimate rather than *a priori* physical reasoning, without use of any equations. However, even these order of magnitude uses of an equation can generally illustrate what is being calculated. The Table of Contents of the book shows the topics covered.

Table of Contents

Each chapter had about 10 worked out problems, some chapters more, some less, in the format 1) QUESTION 2) ESTIMATED ANSWER 3) ANSWER. The third section contained the conventional answer, as it would be done in most textbooks. The second section is the new element discussed here. Many of the examples had two or three parts, of increasing complexity (although in this paper, we will mostly avoid these), in addition to comments or notes, suggesting that the student think further about whether the numbers given in the problem are in fact plausible, or inviting the student to think further about possible extensions. In this paper, mostly examples from the simplest problems, in a fraction of the chapters, are discussed, which suffice to illustrate the general principles of the approach. However, one or two instances of more complex cases or more advanced topics, are also included here to suggest what is possible. Many problems ran to three or four pages, with the complete explanations and comments.

The discussion of the weak acid dissociation problem in the introduction to the book suggests what is involved. The introduction covers certain mathematical approximations. For example, to estimate square roots, a reasonably good approximation comes from expanding, for a > b, $(a^2 + b^2)^{1.2}$ as $a + b^2/2a$. The student does not need to know anything about expansions; it is enough to simply know the rule, and check that $(a + b^2/2a)^2 = a^2 +$

$b^2 + b^4/4a^2$. If a > b, the error is small; the worst case is a = b; try $2^{1/2} = (1 + 1)^{1/2} \approx 1 + ½ = 1.5$, approximately a 6% error from the correct value of 1.41. By the time one gets to $10^{1/2} = (9 + 1)^{1/2} \approx 3 + 1/6 = 3.167$, the approximation is good to three figures ($10^{1/2} = 3.162$). The student should test a few examples to know how valid the expansion is. While pushing buttons on a calculator could obviously give the correct answer in any numerical case, there are times when one has an expression that is the sum of two quantities, one clearly larger, and the approximation gives a general result that is much more useful than carrying the radical expression. What is more, it gets the student used to using approximations, even if the derivation will not come until later in the student's education. Other examples include logarithms ($\ln(1+x) \approx x$ for $x << 1$). Several other useful approximations are included in the introduction.

This approximation to the square root is useful, for example, in solving a quadratic equation, as might be expected. The quadratic equation formula,

$$X = -b/2a \pm (1/2a)(b^2 - 4ac)^{1/2} \qquad (2)$$

because it involves a square root, is an obvious candidate for the use of this approximation. We can combine this with the weak acid approximation we discussed earlier. For that case, the solution, assuming $[HA]_o >> K_d$ is $[H^+] = (K_o[HA]_o)^{1/2}$. Without the assumption,

$$[H^+] = - K_d/2 \pm ½(K_d^2 + 4[HA]_oK_d)^{1/2} \qquad (3)$$

which reduces to the approximate answer if $4[HA]_o >> K_d$. What if $4[HA]_o \leq K_d$? We can use the approximation for the square root to get $[H^+] \approx - K_d/2 + ½(K_d + 4[HA]_oK_d/2K_d) = [HA]_o$ Note that we must take the plus sign for the square root to get the concentration to be positive, and for that matter for the approximation for the high concentration case to appear from the exact answer. The final answer for the $4[HA]_o \leq K_d$ case, **$[H^+] \approx [HA]_o$,** means the acid dissociates completely, so we could have reached the same solution by understanding fundamental chemistry—if the concentration is less than the dissociation constant, the acid acts like a strong acid, dissociating completely. However, it is most likely the student does not have enough experience with chemistry for this to be intuitive, so the use of approximations can make the point, which can in turn be reinforced by the teacher. This would help the student gain a start toward considering what the approximations mean, and the way in which it is possible to attach real chemical meaning to the results of calculations.

The chapter on dimensional analysis is not quantitative, but it is very necessary. One of the most common errors students make is to confuse units. There are normally unit conversion exercises in the first chapter of chemistry first-year texts, but rarely are the students put through the exercise of first determining reasonable values of the answer to a calculation. Each chapter in the Green and Garland book has a brief (some chapters, very brief) introduction going over the fundamentals of the topic of the chapter. However, these introductions are not intended to take the place of a textbook.

An Example of a Worked-Out Estimate, Emphasizing Unit Conversions

This example is not the first in the chapter, so it is not the first the student should work through. QUESTION: On a certain day in New York, the concentration of CO (carbon monoxide) was measured as 2.0 x 10^{-5} g L^{-1}. If the total volume of air over the city is 1.5 x 10^{12} ft^3, how many English tons of CO were present? (An English ton weighs 2000 lbs, as compared to a metric ton which weighs 1000 kg, about 10% more.)

ESTIMATED ANSWER: To begin with, we ignore the difference between English and metric tons—it is 10% different, so not important in an estimate. Let's split the problem up. Again, we have to make two conversions, one on mass, one on volume. The mass conversion is easy, 10^6 g to 1 ton, so 2 x 10^{-5} g L^{-1} = 2 x 10^{-11} tons L^{-1}. (Note that grams are smaller than tons, so there are more of them, 10^{-5} instead of 10^{-11}, in the same volume, 1 L, of air.) *[An obvious error that a beginning student can make is to do the conversion in the reverse direction—one would hope that seeing 10 g L^{-1} would immediately tell the student to go back; this is not always something the student thinks of—the note points out that the direction of conversion should give a smaller number, but does not, in this case, point out that the result of choosing the wrong direction is ridiculous—although it might be good to do so.]* However, we have *lots* of liters *[italic "lots" in the original]* A cubic foot is bigger than a liter. So we are looking for a number which is bigger than (1.5 x 10^{12} ft^3)(2 x 10^{-11} ton L^{-1}) = 30 ft^3 ton L^{-1}. Actually, one foot ≈ 30 cm so 1 ft^3 ≈ 27,000 cm^3 = 27 L. Therefore, we want a number in the vicinity of 30 ft^3 ton L^{-1}x 27 L ft^{-3} ≈ 800 tons

This is the end of the estimate. We forget about the 10% correction to English tons, because we have only one significant figure or not even that, in the estimate. The problem is then worked out in the standard manner, getting 937 tons, rounded immediately to 900 tons (metric). The volume of air over New York cannot be so exact, so at most one significant figure is justified, and there is no real point in bothering to convert to English tons, but one would get 1000 English tons to one figure. This is one of the examples in which the student is invited to consider the plausibility of the conditions and of the given quantities in a problem. Obviously, this problem is only valuable as an exercise, but it is a useful exercise, requiring two conversions, and thinking about the direction of each conversion before carrying it out. When the complete problem is worked out, it checks as to order of magnitude (better, in this case). Before the student pushes buttons on the calculator, the answer is available as a check on whether it is reasonable. If, for example, the student had reversed the conversion from ft^3 to L, and gotten around 1 ton, it should have been immediately obvious that something was wrong (should, because it is not so obvious in this case what the order of magnitude should be—it is more the order of conversions that should be checked). It may seem that this was a fairly oversimplified example, but students do get this type of question wrong often enough to make it worth going through it. By requiring an estimate first, the student must think through the steps, which is normally enough to avoid mistakes. The book gave two significant figures for the volume and the concentration. An astute student might note that the concentration can be measured and averaged over the city, but that the volume depends on some sort of definition of boundary, so that the second significant figure of the volume is somewhat arbitrary, and the concentration must depend on an average, since pollutant concentration is unlikely to be as high in wealthy areas of the city as in poorer areas. However, all this goes beyond what would be expected in a first-year chemistry class.

Summary of Other Problems

From this point forward, we will only summarize problems, showing the main point(s) that illustrate what is being emphasized to the students.

Molecular and atomic mass

1) The isotopes of Cl are given to five significant figures, together with the percentage composition. Of course, the student must realize by looking at the figures, without starting to use a calculator, that if the sample is roughly ¾ ≈35 atomic mass, ¼ ≈37 atomic mass, the result should be closer to 35, but >35, without doing any arithmetic at all. The simplest approximation is to round off the given molecular masses to 35 and 37 and average these using 3/4 and 1/4 as proportions, getting about 35.5. After that the complete calculation, using a calculator, should be trivial. If the answer is very different, the student should be able see at once that the calculation must be redone.
2) In the same chapter, suppose we ask for the mass in grams of an atom of X, given that the molecular mass of AX_2 is 120, and the atomic weight of A is 60. This looks totally trivial, but the student should note that mass in grams, not atomic mass units, is asked for, so the answer should be of the order of 10^{-23}, not 10.
3) Find the molecular mass of $YBa_2Cu_3O_7$. Estimate: note that there are 6 metal atoms and 7 oxygen atoms. If we use 100 for a metal atom, and 100 for 7 O atoms, we get 700. This takes almost no time, and the student should be very suspicious of any result out of the 500 to 1000 range. There is no claim that 700 is actually correct to even one significant figure, although it happens that it is in this case; the answer is 668.9

Gases

Here the book first very briefly reviews the ideal gas laws, but really relies on standard textbooks; it is assumed that the student has access to a standard textbook. There are a couple of van der Waals equation problems also included, which also help the student understand the order of magnitude of the correction. Anywhere in the general vicinity of STP, and past room temperature, the estimates of the total quantities remain unchanged, as the correction is too small to see to one significant figure. However, the problems can be used in estimating the magnitude of the correction itself.

1) Interstellar space has about 1 atom of H per cm^3. The temperature is around 3 K. Find the pressure. *Estimate*: To begin with, this is a one significant figure problem, so there is no extensive calculation in

any case, but it is not so obvious how to get the order of magnitude. By now the student should know that the molar volume of an ideal gas at around 300 K, 1 bar pressure is roughly 25 L (22.4 L at standard temperature and pressure (STP)). If there is a mole in 25 L, the volume for one atom (averages: here we do not introduce fluctuations, so we omit the word averages) is 25/6 x $10^{23} \approx 2.5$ x 10^{-22} L, or, using the fact that there are 1000 cm^3 per L, 2.5 x10^{-19} cm^3 per atom, if we were at 300 K. Pressure should be around 19 orders of magnitude below the 1 atm value at around STP since there is only 1 atom instead of 10^{19}. However, the temperature is 3 K, so the pressure will be another factor of 100 times less; taken together, we should expect a pressure around 21 orders of magnitude below that near STP. Again, this is a one significant figure problem; the estimate of 1 atom per cm^3 is not good to more than this, and the assumption that the gas is at equilibrium with the cosmic background temperature is not locally accurate, except perhaps by accident, either. The estimate in effect is the answer in this case. Nevertheless, it is a very useful problem in getting students used to the idea of dealing in orders of magnitude, and obtaining reasonable results.

2) A syringe is filled with 25 mL of CO_2 gas at 30^o C. The syringe is then immersed in an ice bath at 0^o C, and the pressure remains in equilibrium with the new surroundings. What is the new volume of the gas? *Estimate*: here the number of molecules is unchanged, and the pressure is unchanged, so we only have a drop-in volume with lower temperature. To begin with, the student should note that one gets a drop, not an increase, in volume, as the temperature drops, while all else remains constant. Second, the student should convert to Kelvins, getting a drop from 303 K to 273 K, almost exactly a 10% drop, so the volume drops approximately 10%, and in this case, it makes sense to take the estimate to be pretty close to exact, making the final volume 22.5 mL. To three figures, this is the final answer as well. The difference with the standard approach to the problem, in which the Gay-Lussac Law is plugged into, is that the student should reason through the steps, observing that the volume must drop, and seeing at once that the drop is close to 10%. If this is done before plugging in to the Law, all possible incorrect answers are eliminated.

Standard variations on the same theme include changing the number of molecules and pressure as well as volume and temperature. As noted above, there are also a couple of van der Waals equation problems in the book, but these illustrate the point that when small corrections are involved, the estimate is useful instead for the magnitude of the correction; the overall quantities can be estimated by sticking to ideal gases, except under unusual conditions, such as near the critical point. However, it is at least useful to see at once the direction of the change. The $(p+a/V^2)$ term means the pressure will be less, while the (V-b) term means the volume must be larger, compared to the ideal gas values. For the magnitude of the correction, given the magnitude of the a and b terms makes it possible to estimate the magnitude of the *difference* from the ideal gas case.

Stoichiometry

1) Lavoisier heated tin, Sn, in air, and found that it gained weight. If he started with 10.00 g of tin, how

much weight would it gain? Given: $Sn + ½ O_2 = SnO$

Estimate: first we have to know some basic chemistry: tin reacts with oxygen, but not nitrogen, and the compound formed is SnO. (We ignore the contribution of SnO_2—this is given to the student as an SnO product, without the complication) Then, with one atom of oxygen to one atom of tin, it is only necessary to look at the atomic weights. Oxygen mass is about 1/8 that of tin, so the weight of oxygen added is about 1/8 that of the tin, or around 1.25 g. So far, there has been no calculation other than finding 1/8 of 10. The problem is then worked out formally, and the final answer is 1.35 g. Here, the problem can be talked through, so that the student knows, before resorting to the calculator, that the answer must be pretty close to 1.25 g. Checking that the weight of oxygen is a bit more than 1/8 that of tin tells us that the answer must be >1.25.

Part 2: Extending this problem, Lavoisier found that if he heated 10.00 g of Sn with air in a sealed 10.00 L vessel, the total weight did not change. The initial pressure in the vessel was 1.000 atmospheres. Find the final pressure if the system is brought back to the initial laboratory temperature of 17.0 ^oC.

Estimate: To begin with, gas is being subtracted from what was in the vessel initially, so an upper limit on the final answer is 1.00 atm. If all the oxygen reacted, given that O_2 is about 20% of air, 80% of the air must remain, so a lower limit must be 0.8 atm. Before we do anything, we know the answer must be 0.9 atm ±0.1 atm. We can refine the estimate as follows: We have about 0.08 moles of Sn (by this time, the student should know how to get from grams to moles); each mole of Sn uses 0.5 mole of O_2, hence we use ≈ 0.04 moles of O_2, or, anywhere in the general vicinity of STP, about 1 L volume of gas, meaning about 0.1 of the original volume, so the final pressure should be about 0.9 of the original pressure, or about 0.9 atm.

If the calculation is done to four significant figures, the answer is 0.8998 atm. In order to get the final answer, it is necessary to have the temperature. The student is informed that the fact that the estimate equaled the final answer to three significant figures is just luck, but again having a reasonable estimate allows confidence in the result of a calculation that takes several steps. The 17.0 ^oC allows four figures, when 273.1 is added. Actually, if we assign an error of one in the last place of volume and initial pressure, the answer should really be truncated to three figures. This was not discussed in the book, as error calculation that assumes the maximum and minimum values of the data are not covered, nor the use of root mean square error estimates. These topics are not usually appropriate for a first-year course.

Chemical equilibrium: There are several types of problems in this category. Essentially these are problems that involve equilibrium constants: K_{eq}, including K_a (acid dissociation), K_{sp} (solubility products), K_p for gas pressure equilibrium, and related problems. Although this chapter comes before thermochemistry, the introductory material includes the relation

$$\Delta G = -RT \ln K_{eq} \quad (4)$$

without much explanation of ΔG, but enough to do some problems.

We start out by pointing out that if K_{eq} approaches zero, we have almost entirely reactant, if $K_{eq}>>1$, we have mostly product (all product if K_{eq} reaches infinity, but we do not discuss in this section the fact that exactly zero or infinity is impossible—that requires more of thermodynamics than we can use in this chapter—however, the student might surmise this from the fact that

$$K_{eq} = [P1][P2]/[R1][R2], (P_i = \text{products}, R_i = \text{reactants}) \quad (5)$$

or similar forms for other stoichiometries, together with the ΔG relation. If $K_{eq} \approx 1$, ΔG must be fairly small, from the log relation. "Small" must be in relation to RT. If $|\Delta G| >> RT$, $K_{eq} \approx 1$ cannot be correct.

This said, the main point of the chapter concerns the K_{eq} calculations. For gas calculations, K_p is given, as is the relation between the K_p and K_{eq}. Some examples:

1) This problem is taken from a 1913 paper (6) on the dissociation of $PCl_{5(g)}$ near 500 K:
$PCl_{5(g)} \rightarrow PCl_{3(g)} + Cl_{2(g)}$

α is the fractional extent of dissociation, so that if we have n moles of PCl_5 to start, we have nα of PCl_3 and of Cl_2, and 1 – nα of PCl_5. *The problem is to find ΔG_p at 500K*. The data are given in Table 1:

Table 1. Temperature-Pressure relation for PCl_5

T (K)	p(mm)	α
462	762.8	0.244
485	814.7	0.431
534	1214.5	0.745
556	1370.1	0.857
574	1358.6	0.916

ΔG_p is the value of ΔG in terms of pressure, and is independent of total pressure. The relation between this and the ΔG_c (in terms of concentration) is given earlier in the chapter. If the amount of dissociation is about half, the ΔG value must be small in absolute value—there is not much difference between reactant and product equilibrium concentrations. From the looks of the data, at 500 K the α is around 0.5. This suggests $K_p \approx (.5)^2/(1 - .5) = 0.5$, so $\Delta G \approx -RT \ln (.5) \approx 3$ kJ. The actual answer, which requires a rather extensive calculation, is +2.6 kJ. Again, the approximation happens to be closer than it has any right to be. However, that the value should be small is apparent without even this much effort. If the value were much greater than 20 kJ, or much less than -20 kJ, the degree of dissociation would be nowhere near 0.5 (the student should by this time know that RT near 300

K is ≈2.5 kJ, so should know that around 600 K, RT≈ 5 kJ). Once we have this much of an estimate, we can proceed with some confidence that the answer must not be large in absolute value, probably ≤ RT.

2) The idea of free energy of formation was explained in the introductory material for this chapter. Hence, the student should know that if we give the free energy of formation of CO, it is the free energy of reaction for

$$C_{(S)} + ½\, O_2 \rightarrow CO \qquad (6)$$

Question: Given total pressure =10 atm, and ΔG_p = -137 kJ mol^{-1} find the final pressure of O_2 and CO. *Estimate*: We are able to find the partial pressure of CO given the total pressure. In this case, the ΔG_p is far greater than RT, -137 kJ mol^{-1} and is negative (the free energy of formation of CO is given).

A large negative ΔG_p implies that the product, CO, will completely dominate the mixture. We expect $p_{CO} \approx 10$ atm. Since we only have three significant figures, and at 300K, 137/RT > 60, so that we have something like $e^{-60} \approx 10^{-24}$ for the pressure of O_2 (this is not exact - and is not the way to do the exact calculation, but for the estimate it is good enough). If there is so little O_2, all the rest must be CO, so its pressure is equal to the total pressure to more than three significant figures, making p_{co} = 10.0 atm. Again, the calculation is fairly complex if it is done properly, which allows room for mistakes. If the estimate is done first, an erroneous result will be immediately apparent.

3) Mix 100.0 mL of 0.1000 M HAc with 100.0 mL of 0.0750 M NaOH. Find the final pH. The pK_a of HAc is 4.75

Estimate: To begin with, the student must recognize that this is a buffer problem; we assume that the student does realize this. NaOH is a strong base and HAc a weak acid *[presumably the student already knows this, and the fact that the pK_a is given for HAc should be enough of a reminder, if one is needed]*. There is more than half as much strong base as acid, so this will form more salt of the acid than there is acid remaining. This already tells us that the ratio of $[Ac^-]/[HAc]$ >1, so we must have pH > pK_a. Since the ratio is not close to an order of magnitude, the difference will not be huge. We expect a pH > 4.75, but not by a full pH unit, so around 5. In solving the problem, remember that the final volume is 200 mL, so the concentrations are half those in the two starting solutions.
The final answer to the problem is pH = 5.23.

Thermochemistry

This chapter has 8 pages of introductory material, since we were not satisfied with the presentation in some texts. There is a brief introduction to the most important thermodynamic quantities, to calorimetry, to the Laws, and to definitions (reversible/irreversible, path independence, etc.). After this, it is possible to introduce problems knowing that the student has the basic concepts at least defined.

1) Part 1: For the reaction:

$$CH_{4(g)} + HCl_{(g)} \rightarrow H_{2(g)} + CH_3Cl_{(g)} \quad (7)$$

the free energies of formation, ΔG_f^o, are: CH_4: -50.79 kJ; HCl: -95.27 kJ; CH_3Cl -58.5 kJ.

Estimate: We can just look at the values—as a rough approximation the CH_4 and CH_3Cl values cancel, leaving a large negative value on the left, so the overall result must be around +95, but less because ΔG_f^o of a product is more negative than that of the reactant we compared it to. The first thing the student should notice is that with a large negative value on the left, the overall result must be >0.

Actually, setting this up is almost trivial, and the answer is +87.6 kJ.

Part 2: Find the final partial pressure of CH_4 and of HCl if their initial partial pressures are both 10.0 atm, and the initial partial pressures of the products are zero. T=298 K. All reactants and products are gases, and can be assumed to be ideal. Then get the partial pressures of the products.

Estimate: With such a large positive ΔG_f^o the reaction hardly gets started. Just looking at the exponential term $\exp(-\Delta G^o/RT) \approx \exp(-35)$, we see without doing any work the final partial pressure of the reactants is almost as large as the initial partial pressure, 10 atm. More than three significant figures would be needed to see a difference. We can use this to get the final partial pressures of the products easily, since the final partial pressure of the reactants is known. The one estimate we make is to note that the final partial pressure of products must be very small.

As there is no change in the number of moles, $K_c = K_p = \exp(-87.6/(8.3*298)) = 4.49 \times 10^{-16}$. Given the stoichiometry, let P = the final pressure of H_2 = final pressure of CH_3Cl, so $K_p = P^2/10^2$, giving $P = 2.12 \times 10^{-7}$ atm.

In this case, we skipped the estimate for the products, as there was only one step, and we only observe that P<<1 is satisfied. We could have immediately realized that we needed < e^{-15} for the pressure from the e^{-35} we estimated for K_p. ($e^{-15} = 3 \times 10^{-7}$). This could have been used as a check, or an estimate. At the least, the student should see that this is reasonable.

This problem, with its two parts, is interesting in that it requires the student to think through information in the problem and realize that much more can be obtained than the original, rather simple, thermochemistry problem.

We could add a third part, asking, given the number of moles that actually reacts, what the volume must be. Then this also becomes a very simple stoichiometry problem, and a somewhat more interesting gas law problem. In the latter part, the student is reminded of a short cut to estimate volumes in such problems, with $V \approx 25\ (n/p)$ L near room temperature, and use only one significant figure for n moles and p bar or atm (bar and atmosphere are equivalent for estimates).

2: A solid melts to an "ordinary" liquid, which then boils. Given: $\Delta H_m = 12.5$ kJ mol^{-1}; $\Delta S_m = 37.5$ J mol^{-1} K^{-1}; $\Delta S_b = 85$ J mol^{-1} K^{-1}; MW = 120; T_b =393 K. Find: a) T_m b) ΔH_b per mole c) ΔH_b per gram

a) *Estimate:* For T_m we can use $\Delta H_m = T_m \Delta S_m$. Before we even start doing arithmetic, though, we should notice that we have an immediate upper limit, in that T_m will be less than T_b = 393 K. If we get anything greater than 393 K for T_m when we do the arithmetic, we should look for a mistake. Also, "ordinary" liquids generally have a liquid range under 100 K at ordinary pressures (sometimes even less at 1 atm, like CO_2, which sublimes, and has no liquid range at 1 atm). Salts and metals are also different, with much larger liquid ranges. Many simple salts have relatively high melting points (there are some complex salts that are ionic liquids at room temperature), and metals mostly have melting points above 393 K (exceptions include Hg and Ga, and, near the upper part of that range, Na and K). Knowing some elementary chemical properties helps with the estimate in this problem. Now that we have thought of all this, let us return to our "ordinary" liquid, and find that T_m = 12500/37.5 = 333 K, a reasonable value (remember that ΔS is in J, ΔH in kJ, so don't forget to adjust the decimal accordingly).

b) *Estimate:* $\Delta H_b = T_b \Delta S_b$. This is almost trivial, but we must expect a value greater than ΔH_m. In one sense, this is even more trivial than usual, as $T_b > T_m$ and $\Delta S_b > \Delta S_m$. ΔH_b = 33.4 kJ. This is about $3\Delta H_m$, which is reasonable. The value of ΔS_b = 85 J K^{-1} mol^{-1} is found, within a few kJ, for almost all "ordinary" liquids at around 1 atm pressure. The entropy of a gas is much greater than that of a liquid, usually, and therefore, the $\Delta S_b = S_g - S_l$ is essentially that of the more or less ideal gas at the boiling point, where the liquid comes apart into gas molecules. The reason different substances, with different T_b, have about the same entropy of the gas phase at the boiling point, is more complicated, and not part of the first-year course. If the liquid is highly ordered, such as water, the ΔS_b value is larger, as water still has more order which is destroyed at the boiling point, hence lower liquid entropy, than an ordinary liquid. The difference is not huge: ΔS_b (water) = 109 J K^{-1} mol^{-1}. However, this is enough to remind us that water is more ordered than an ordinary liquid. The $\Delta S_b \approx 85$ J K^{-1} mol^{-1} value is known as Trouton's Rule, and is fairly general for ordinary liquids. Metals and salts do not follow Trouton's rule. The rule implies that $\Delta H_b \ \alpha \ 1/T_b$ over a range of liquids. This is not the same as the Clausius-Clapeyron equation, which relates boiling point of a single liquid to pressure.

c) *Estimate:* Grams are smaller than molar mass, in this case 120 times smaller, so all the molar quantities must be divided by 120 to get the per gram values. It is only necessary to remember that grams are smaller than moles to get the relative order of magnitude correct, *Electrochemistry:* This topic comes near the end of the course, and many of the concepts that had to be introduced earlier can now be assumed known by the students. By this time, thermodynamics, equilibrium, and kinetics have all been covered. The students know what a redox reaction is, and presumably should be able to handle quantities of charge, meaning numbers of electrons. There are 96,520 Coulombs (C) to a mole of electrons, and if one simply keeps a factor of 10^5 in mind, converting from charge to moles is quick. Since 1 ampere (A) means 1 C s^{-1}, it takes 10^5 seconds for 1 A to run a reaction long enough to produce a mole of product, if it is a 1 electron reaction. It is not difficult to correct if 2 or 3 electrons are involved, or, as is typically the case in laboratory experiments, the current is less than 1 A. Finding the order of magnitude for any problem involving a reaction driven by electric current is straightforward.

Redox potentials are a different set of problems. Here the energy is involved, and it is often necessary to translate from volts to kJ; the student must know that volts x charge is energy; specifically, 1 C x 1 V = 1 J. Again, there are a couple of conversion factors that enable the student to be sure of being in the right neighborhood. For a mole of electrons, $\approx 10^5$C, therefore a redox reaction that has a difference of half-cell potentials of 1 V will have ≈100 kJ difference in energy, and will go to completion (or, will not go at all, if written in the reverse direction). For a one electron reaction it takes approximately 60 mV to move the equilibrium one order of magnitude, for two electrons, 30 mV. This is reflected in pH meters, which are actually high input impedance voltmeters, and determine the pH from the potential produced by an electrode sensitive to $[H^+]$. One uses concentration without correcting for activity coefficients at first year chemistry level.

Problem 1. Consider the reaction

$$Cd^{+2} + Fe \rightarrow Cd + Fe^{+2}$$

The half-cell potentials are

$$Cd^{+2} + 2e \rightarrow Cd \qquad E_{1/2} = -0.403\ V$$

$$Fe^{+2} + 2e \rightarrow Fe \qquad E_{1/2} = -0.440\ V$$

Find the ratio of concentrations $[Fe^{+2}]/[Cd^{+2}]$ at the point that the reaction has no tendency to move in either direction (i.e., at equilibrium).

Estimate: The reduction potentials are not very different, so the ratio should not be orders of magnitude away from 1. On the other hand, $|E_o| > 30$ mV, and it is a two-electron reaction, so the ratio to balance E_o must be >10 (now check the sign and the ratio—or is it <0.1?). To have the reaction have no driving force, that is for $\Delta G = 0$, we must have

$$= E_o + RT/2F \ln [Fe^{+2}]/[Cd^{+2}] = 2.303\ RT/2F \log_{10} [Fe^{+2}]/[Cd^{+2}]$$

where F is the Faraday, 96,520 C. At room temperature, we know 2.3 RT/2F ≈ 30 mV at around 300K, so the ratio must be >10 (careful of the sign-- E_o is positive (reverse the Fe half reaction to get the reaction as written; one half reaction must be reversed to make the number of electrons cancel, a point that must be explained to the student, especially for cases where a two electron half reaction and a one electron half reaction are involved), making $\Delta G_o<0$, so the reaction goes to the right and there is more Fe^{+2} than Cd^{+2}, about one order of magnitude more. The actual answer is 17.8.

Problem 2. Given the following half reactions

$Cd^{2+} + 2e \rightarrow Cd$	$E_{1/2} = -0.403$ V
$Fe^{+2} + 2e \rightarrow Fe$	$E_{1/2} = -0.440$ V
$Cs^{+} + e \rightarrow Cs$	$E_{1/2} = -2.923$ V
$Ag^{+} + e \rightarrow Ag$	$E_{1/2} = +0.799$ V

Part 1: Find the largest voltage battery that can be made from two of the half reactions

Estimate: This part is pretty trivial, if you remember that the signs reverse when you reverse the direction of the half reaction from reduction, as shown, to oxidation. The battery voltage is the difference between the oxidation and reduction half reactions. We almost certainly want to use the Cs half reaction, with the largest half cell voltage. It becomes positive when we reverse it. Add this to the one positive voltage, the one half cell that "wants" to be reduced to the metal, and we get 3.722 V. This part is one case where it is only necessary to understand what the question is, and no numerical exercise is worth the effort.

Part 2: What is the equilibrium constant for this reaction? Answer to the correct number of significant figures.

Estimate: This battery has a huge E_0 so we expect the reaction to go "to completion". In other words, the battery reaction will lead to essentially all $Ag_{(s)} + Cs^{+}$, and almost no Ag^{+} and $Cs_{(s)}$. The solids do not come into the equilibrium constant, so $K_{eq} = [Cs^{+}]/[Ag^{+}]$, and we know that it will be huge, around $10^{(3.6/0.06)} \approx 10^{60}$ at equilibrium. We have already seen a couple of cases in which we had astronomical numbers like this. It means that there would be no Ag^{+} with a mole (actually many moles—even an amount large compared to the size of the earth) of Cs^{+}. It is however, possible to do the calculation, although we won't bother here. One thing this does tell us is that if it were possible to carry through the calculation, we would get a nonsense answer, in real physical terms. However, why would we want to go to equilibrium? A battery that reaches equilibrium is, by definition, unable to do work, hence dead, until recharged. This system would work as a battery at a pair of concentrations that had a finite concentration ratio. We can calculate the voltage as a function of the ratio. As an exercise, write down an expression for the voltage as a function of the ratio $[Cs^{+}]/[Ag^{+}]$.

This concludes simple examples of problems from several chapters, which serve as a sample of the overall type of problems; they are pretty much the same as ordinary problems from texts. In some cases, we use extreme conditions, as in the 1 atom per cm^3 gas law problem. These have the aim of causing students to consider what the numbers are actually telling them. In addition, there are a few more advanced problems, possibly useful in Honors sections; here is an example.

A more advanced example: If we consider a very small volume, fluctuations can be significant. Suppose we explain to the student that fluctuations in the number of molecules in a volume in contact with an external reservoir are of the order of the square root of the number of molecules. Consider a bacterium, with volume of roughly 10^{-17} $m^3 = 10^{-14}$ L. Suppose a molecule is present at a concentration of 0.4 M (something in the range of salt concentration, for example). Then we have $0.4 \times 10^{-14} \times 6 \times 10^{23} = 2.4 \times 10^9$ molecules. The fluctuations are then roughly 5×10^4 molecules, or about a fraction of 2×10^{-5} of the molecules in the bacterium, probably not enough for the bacterium to worry about, even if a much larger fraction than one would get in a macroscopic system. However, some substances are present in smaller quantities, but are still important. If you have a molecule that is present in 100 nanomolar quantities, replace 0.4 in the calculation above with 10^{-7}. Then there are about 600 molecules; taking the square root (25 is close enough) and dividing by the total number, 600, we get fluctuations around 4%. This is not obviously trivial. It also means that carrying a calculation past 2 significant figures is not likely to produce a meaningful result. While this is an advanced topic in that it requires giving the student the concept of fluctuations in concentration, and pulling the square root relation out of the air—deriving it in a first-year class would definitely be going too far--it does reiterate in a new context that examining the meaning of a calculated number can be critical. One should also be careful to examine the conditions of a problem. A volume of 10^{-14} L is on the edge of the minimum size that makes sense for a bacterium. If the problem had stated the bacterial volume as, say, 10^{-17} L, it would be necessary to ask whether such a bacterium could exist. While this example might be restricted to the honors section of a first-year class, other cases in which ordinary systems are given impossible properties could be used to call the student's attention to the point that one must make sure that the physical conditions associated with the numbers in a problem are plausible. Once again, the actual calculations are not the point of the problem.

*Kinetics***:** This can include discussion of reaction mechanisms.

Problem 1: Given: Step 1: O3 = O_2 +O fast, reversible

Step 2: O + $O_3 \rightarrow 2\,O_2$ slow

Find the overall reaction mechanism.

Estimate: Unlike essentially all the previous examples, this is not a numerical example. The student must think through what the problem is asking. First, it is useful to have the overall reaction, which the student should get from adding the two steps: $2\,O_3 \rightarrow 3O_2$. The O atoms are not included in the product, as they are used up in the second step. Then, the student can observe that the second step is slow, so both O_3 molecules must be in the rate step. If O_2 increases, the first reaction must reverse, so we should expect that the rate is inversely proportional to O_2. This appears to give a rate law:

$$\text{rate} = k_r\,[O_3]^2/[O_2]$$

At this point, we have a plausibility argument, but the student should understand that each of the two overall steps given may be complex, but this is not yet proof. Still, the putative rate law is at least plausible.

Answer: The student would have to find a steady state approximation for [O], and use this in the slow step. The answer turns out to be the estimated rate.

Problem 2: Given that the energy of activation for the reaction 2 HI → H_2 + I_2 is -185 kJ, and the heat of formation of HI is -5.65 kJ. Find the activation energy for formation of HI (i.e., the activation energy of the reverse reaction from H_2 and I_2.)

Estimate: The forward and reverse reactions cannot be that different, because 185 is much greater than 6, which is the difference between the reactants and products. There are two HI molecules, so for one HI, the reaction should be HI → ½ H_2 + ½ I_2, which of course will have half the activation energy, or 92.5 kJ. Since the energy of formation of HI <0 it will add to the reverse reaction energy, meaning that it must subtract from the absolute value of the activation energy. The estimate is then a little **less** than 92.5 kJ

Answer: We have practically done the entire problem. The answer is 92.5 – 5.7 =86.8 kJ. We have three significant figures. However, it is worth drawing a diagram to show how the subtraction works.

Discussion

This is a sampling of the type of problems that can be estimated; there are such problems in every topic. As can be seen from the Table of Contents, there are more chapters, therefore topics, than are illustrated in this summary of problems. In each chapter that is sampled, there are about five times as many problems as are given here. However, this much is sufficient to show the approach to finding estimates; in the book the conventional solution to each problem is also given in detail; here we only give the result of this calculation, as going through the standard solution of first year chemistry problems is routine. It is important for the student to compare the standard solution to the estimate. Thus, students should understand why one would first make an estimate, and how this helps in understanding how the estimate is useful. While there are qualitative chemistry problems, as in organic chemistry, where finding reaction mechanisms or synthetic paths does not require numerical calculations, much of chemistry, especially in the first year, is quantitative. Students who are able to understand that numbers have physical meaning in the context of chemistry problems, and understand that the orders of magnitude of the answers must be reasonable, can generally continue on to more advanced material. Usually, a student who tries to survive by memorizing equations will make unreasonable errors. In addition, because such students did not understand the material, they will be unable to advance to new material that builds on the material that they never understood in the first place.

Teaching students to pay attention to the orders of magnitude of the quantities being calculated, and to recheck their answer against the physical meaning of the answer, mainly requires calling their attention to the matter, and giving them some examples to work from. It is a matter of getting the student to think about what the numbers mean. The examples given here suggest how this can be done. However, any problem in which the numbers have physical meaning would be a candidate for this approach.

Whether the best approach to bringing this to the student's attention is a separate book with such problems with estimates, or whether it is better to have the problems incorporated into the main text, is another question. In principle, incorporating formal estimates for most topics into standard texts seems to be uncommon; however, it would probably make more sense than having the estimates exiled to a supplementary text. The book on which this paper is based is out of print and no longer available, and would probably need revision in any case before any attempt at distribution were made. However, by taking examples from this book, one can see the possibility, and the means, of using these estimates to force the student to think about the physical meaning of the numbers. This appears to be different from any of the solutions to chemistry problems available on the internet, which we may take as a reasonable approximation to what is shown in most textbooks. None of these that this author has found takes an approach similar to what is proposed here. On the internet, there are many sample problems, carefully worked out, but not checked as to whether the answers are physically or chemically reasonable; they generally do not discuss the physical meaning of the numerical values. Such examples do not help with the problem of understanding the physical meaning of numbers.

Conclusions

1) Students need to understand that numerical values in chemistry problems have physical meaning.
2) This can be accomplished in part by requiring the students to estimate at least the order of magnitude of an answer, to make sure that the answer is not ridiculous
3) Almost every topic in introductory chemistry has sufficient quantitative character for consideration of estimates to be applicable.

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The Role and Importance of Using Technology in Teaching

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Abstract: This study aims to make an in-depth analysis of the prevalence and nature of the phenomenon of Internet use in teaching. The selected grades are grades VI to grade IX which in the literature are known as lower secondary education. The researcher has used the mixed method model, including qualitative and quantitative research strategies. The study involved n = 164 students and n = 117 teachers from eleven 9-year schools in the city of Prishtina, and n = 117 school staff. The results from the questionnaires with students that are quantitative in nature showed that the use of the Internet in schools is an integral part of the schools taken in the study. Most of the teachers stated that they had not received training to deal with the new models of application of technologies in teaching and a considerable part of them stated that they were unsure how to react in case an obstacle appeared in the non-functioning of technology during the lesson. The sample selected in the research consists of a total of 281 respondents, of which 117 were teachers and 164 students. There are a total of 117 employees and leaders of educational institutions and 164 students who will serve as samples.

Keywords: Information technologies, Education, Application, Teaching, Programs

Introduction

Information Technology is a key element in our functioning as a society. Nowadays, the impact of IT is becoming more and more pervasive. This impact has not neglected the education process in the country, education which is the focus of the treatment of this study. Information technology infrastructure is poor in almost all educational institutions. Much data is stored and archived mechanically and there is not yet a general coordination of the technological infrastructure. In this context, the development of e - education or online education is still underdeveloped and there is a need to take concrete action in this direction as an important step towards achieving inclusion and lifelong learning.

Research Methodology

Purpose of the Study

The purpose of this study stems from the need to conduct a study on the use of information technology in

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teaching. It aims to make an in-depth analysis of the frequency and nature of the phenomenon of how much is applied and practiced the level of use of electronic devices in teaching during school to students in lower secondary education in the city of Prishtina and the attitudes and reactions of teachers. on this phenomenon.

Based on the structure stated for the realization of this paper, initially the research is based on the description of the factual situation and the acquaintance with the technological concepts and their application, in this part is applicated the method of documentation analysis. First, we collect the documentation on the data and results already existing, related to the problem. This method has a dual approach. First, we have the opportunity to apply the experiences so far. Second, it starts with something new, related to the experimental method, which is used in the functioning of proposals for IT application in Kosovo for education, achieving goals and reviewing the results. Of course, this process requires description to discover the causes, consequences, benefits and conclusions, ie descriptive methods. The case study is also used in the framework of the paper as a method of illustration and verification of the descriptive method of documentation.

Listed:

- Documentation analysis method
- Case study method
- Descriptive method

The Need for This Study

Schools are complex organizations, as they serve different functions. It is understood that in principle they have the function of academic education, but, in addition, schools are expected to have the function of socialization. The school, except inspiring academic achievement, also enables the fulfillment of different needs of students, from complex social and emotional needs to basic needs for warmth and shelter.

Kosovo is a country with a high degree of technology utilization. According to a report by the Association for Information and Communication Technology in Kosovo (STIKK), it is estimated that 76.6% of the population of Kosovo are Internet users, mainly for entertainment purposes (STIKK, 2013). This scale is at the level of developed countries. On the other hand, in Kosovo schools there is a computer per 46 students, while 57% of the teaching staff are trained for ECDL (Zylfiu, 2016). Such a situation requires faster movement towards the application of ICT in the classroom, as the opposite may reduce the importance of the school for the future of students.

MEST has drafted the Strategy for e-learning and has equipped schools with various teaching tools and equipment. A significant number of schools in Kosovo are equipped with computers, projectors, equipment for various cabinets, as well as other tools that enable the development of students' competencies. MEST statistics show that 44.4% of schools have technological equipment. However, the problem of poor maintenance of ICT equipment remains. Moreover, despite the investment, the number of teachers who are able to prepare electronic content and use it in the teaching process is very limited.

Besides, many studies around the world have clearly shown the negative effects of not applying new teaching techniques.

The education system is characterized by a low use of information and communication technology and modern technology is not properly integrated into the curriculum, teaching or management of education. The implementation of the strategy for the inclusion of information and communication technology has not progressed as for seen by the initial plan. The computer-student ratio in Kosovo is 1:46 and is much lower compared to the EU average, where 3 - 7 students use a computer (STIKK, 2013). In Kosovo: 1 computer = 46 Students. In the EU: 1 computer = 3 - 7 Students

There are three steps of ICT inclusion in educational institutions in Kosovo:

1. Development of ICT infrastructure and services
2. Learning to use it (teachers and students)
3. Use to learn.

Importance of the Study

The safety of all members in a school environment is an essential condition for presenting the best, most popular and most successful in terms of the values of an effective school, which increases the academic welfare, emotional and social well-being of its students. . The Convention on the Rights of the Child emphasizes the importance of protecting the quality of life of the child and their right to be educated in a safe environment, free from violence, without harassment and where they are not ignored or neglected. Applications of technologies such as video projector, smart board, computers, software, internet, tablets, mobile etc. have been placed into the education system, teaching resources have changed significantly. Using technology and the constructivist approach together, the teacher ensures better integration and utilization of technology tools in the classroom in appropriate and effective ways, giving teaching / learning the necessary tool to improve teaching methods that focus on their student.

Technology can help and helps the learner to develop all kinds of skills from the simplest to the most complex. However, for technology to be successful, the teacher must make informed choices about the pedagogical approach, student needs, and learning outcomes. For the teacher, as important as it is to know what he will use technology for, it is equally important to know how learning can be improved through technology. Integrating technology into the classroom means a lot to different teachers. When teachers are asked if they integrate technology into their subjects, they give numerous answers such as:

- I use the computer in the classroom to reinforce the issues I have explained.
- Students use the computer to find information.
- Students use the word to do homework.
- Use power-point to make presentations in class

But the real issue does not lie in whether technology is used in the classroom, but whether it is being used to improve the learning process (Benek & Akcay, 2019; Kim et al., 2021 ; Ntemngwa & Oliver, 2018; Portali Shkollor, 2018). A well-designed computer curriculum is engaging and interactive and has two important qualities for students who have difficulty in concentrating or have a residual history and have lost their motivation. For example, a math or spelling program may use images (pictures), sounds, and features of the nature of the game to keep the attention of a student with deficit disorder. Digital interactive media programs teach deaf people how to use sign language. Many programs do not use sound, so students with hearing impairments can take full advantage of visual lessons. Students who have difficulty reading can use programs that "pronounce" unfamiliar words to them, if they click on them. With this opportunity for instant help, students are more likely to practice reading, which they need to prevent lagging behind (Woolfolk, 2011).

Technology is more than just another way of presenting information; it is the system through which information is presented. Technology, as part of the constructivist theory of teaching, is the framework of the teaching / learning methodology which provides the ability to support all the major forms of this theory (Portali Shkollor, 2018).

Methodology of Study Organization

This paper introduces us to the purpose, general and specific objectives, as well as the research questions of the study. He then explains the research strategies that have been selected as a result of the research model, acquaints us with the instruments used to conduct the study and with the tests performed to ensure its validity and reliability, with the selection of the sample, with the collection and with data analysis, as well as with ethical issues for the subjects and with the limitations of the study.

Purpose and Objectives of the Study

The main purpose of this study stems from the need to conduct a study on the phenomenon of using the level of new technologies in teaching in the context of Kosovo. It aims to make an in-depth analysis of the frequency and nature of the phenomenon of technologies in 5-9-year schools in the city of Prishtina, as well as the attitudes and preparations that teachers have for this phenomenon. The selected grades are grade V to grade IX, which in the literature is known as lower secondary education. These classes were selected because according to the world literature have the highest percentage of internet use.

Research Methods

The researcher has used the mixed method model, including qualitative and quantitative research strategies. Gay, Mills & Airasioan (Gay, Mills & Airasioan, 2009) claimed that the goal of mixed methods is to create a synergy and power that exists between qualitative and quantitative research methods. In this model, qualitative and quantitative data were collected simultaneously throughout the study. Referring to O Donout and Punch (O`Donoghue & Punch, 2003), the mixed method explains human behavior more clearly and comprehensively, studying it from more than one point of view and giving it more details and a more balanced picture of the situation. Researchers usually use the mixed method because they think that the data obtained from one method alone would be insufficient and inadequate to present the whole problem.

Quantitative Data

Since the study is basically of the descriptive type, then, to understand in more concrete terms the degree and level of use of technological equipment with students in the classroom, quantitative data were used. Quantitative data were obtained using anonymous questionnaires in students from grade VI to grade IX, as the best method for data collection, due to the nature of this study.

Sample Size and Selection

The definition of a sample is based on Greveter and Forcanoja (Gravetter & Forzano, 2003), according to whom a sample is a group of individuals taken from a certain population, who constitute the study population. 26 Schools were selected through a stratified / stratified random sampling among the 9-year schools of the city of Prishtina from grade VI to grade IX. This population does not include 9-year private schools and schools with non-classical profile (artistic or special). In order for the margin of statistical error of the sample not to be greater than +/- 3.3%, with a confidence level of 95% (p = 0.05) it was necessary for this /for the correct calculation were taken statistical tests to be used, the criteria for the selection of the sample and the fact that in a class with an average of 35 students-40 students 27, the smallest number of questionnaires that had to be distributed to make an accurate measurement of the phenomenon about the application of teaching techniques according to new teaching technologies was twenty questionnaires (half of the class) for each class, by increasing the number of sample in respondents, of which there were 117 teachers and 164 students. There are a total of 117 employees and leaders of educational institutions and 164 students.

Quantitative Data Analysis

The data collected from the questionnaire was thrown into a program called CSPro (CENSUS47 and Survey Processing System-Census and processing surveillance system). This program can be used to cast, publish, calculate and disseminate census data or other studies. The database created in the CSPro program was exported for further analysis in the 19th version of the SPSS program (Statistical Package for the Social Science).

This study is essentially quantitative and aims to provide a clear picture about the level of use of new technologies in teaching with students in lower secondary education in the city of Prishtina. The results of this chapter are divided into four sections, pertaining to the first four objectives of the study.

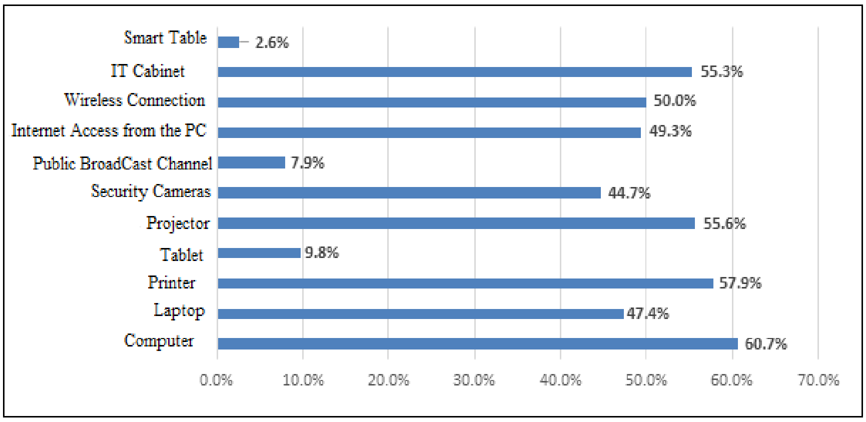
1. The first section gives us clearer information which technologies are most practiced in schools.
2. The second section gives us an overview of the application of new teaching techniques,
3. The fourth section gives us a general overview of some specific characteristics (such as student popularity at school, race, level of student approval and self-assessment of school learning outcomes), which make a student to be better prepared in the application of new technologies.

Employees and leaders of educational institutions involved in the research are from Kosovo. In the e-mails that they declared as personal, the instructions and the link to access the questionnaire were sent to them. There are 117 of them who have responded to the request. The reason why the research is focused on them is that the basis of general knowledge and knowledge is gained in pre-university education, while later only profiling is gained, so mainly the teachers are primary and lower secondary schools.

Results and Findings

Information Technology that can be found in Educational Institutions

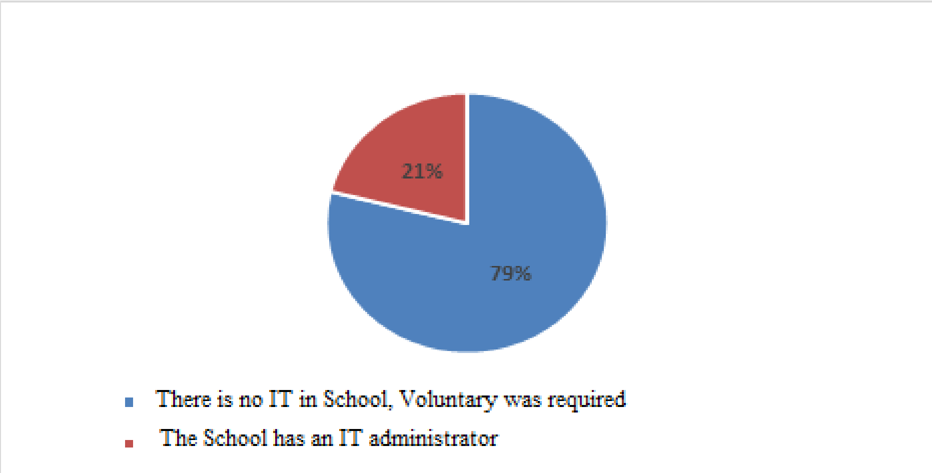
Recently, state investments and foreign donations in Kosovo schools have been made mainly in equipping schools with computers and computer laboratories. The results from this research point show that the Desktop computer as an electronic device is found in about 60% of schools while the Laptop as a more compact device in a smaller percentage.



Graph 1. Technologies that can be encountered in Educational Institutions

Problem Management with Information Technologies

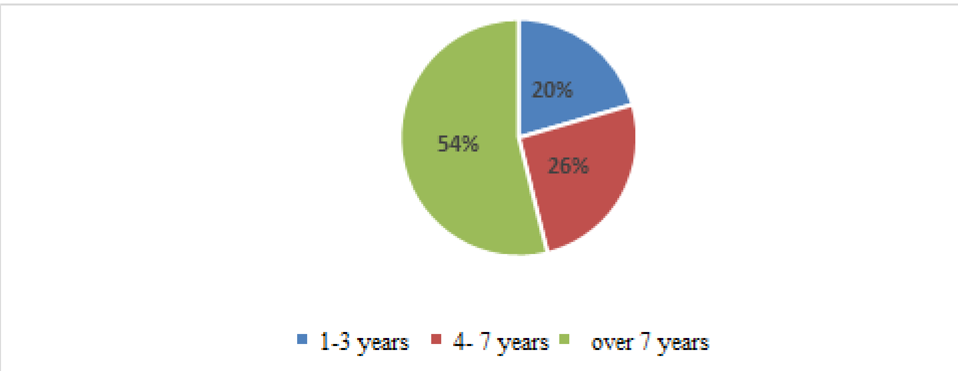
These devices and technologies require proper use and constant maintenance. The situation in Kosovo in terms of addressing these issues does not seem to be good, this could lead to another situation where we can see and touch the equipment but not work with it because there is a risk that they will not be in functional condition. So for the management of problems with information technologies, teachers in the largest percentage about 79%, have reported that the school does not have IT, they fix the problems voluntarily.



Graph 2. Information Technology Problem Management

Obsolescence of Equipment

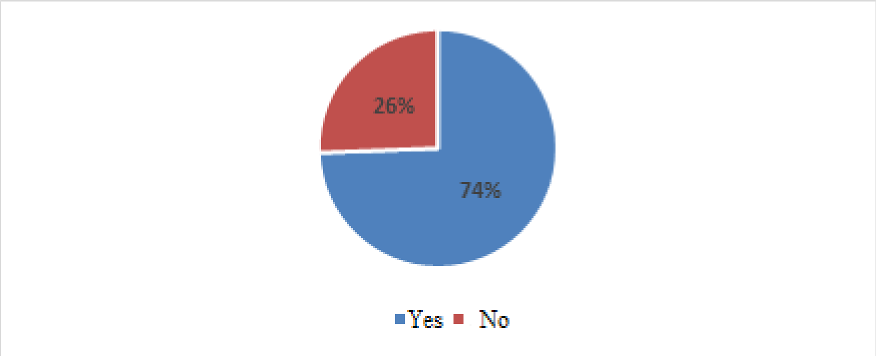
Asked about the age of technological equipment in the respective educational institutions, most of them, more specifically 54% state that they have technological equipment over 7 years old since the last investment have not received new investments, 26% state that they have equipment with age of investment from 4 to 7 years and 20% who have new equipment 1 to 3 years in terms of use.



Graph 3. How old are the technological equipment in your school?

ICT Trainings

Approximately 74% of teachers who state that they have held trainings in the field of ICT and 26% of them state that they have not been part of these trainings.



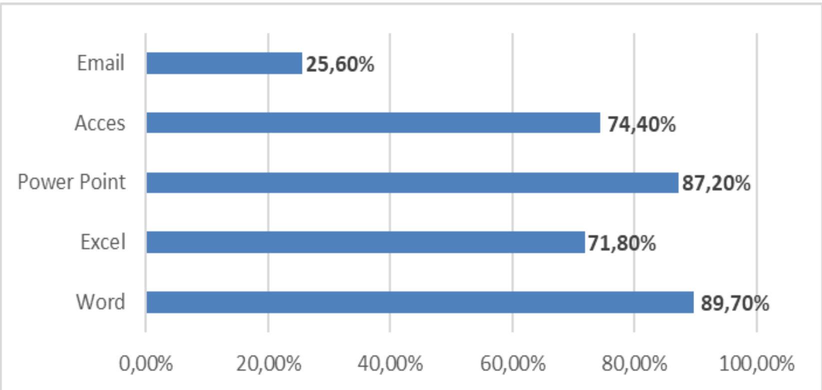
Graph 4. Have you completed ICT trainings?

Computer Use

For the level of computer use, a form of self-assessment from 1 to 5 was required. 21.1% were declared as excellent users (5), 39.5% were declared as level 4, 31.6% were declared as level 3, level 2 were declared 2.6% and 5.3% declared themselves as weak users.

Programs Used

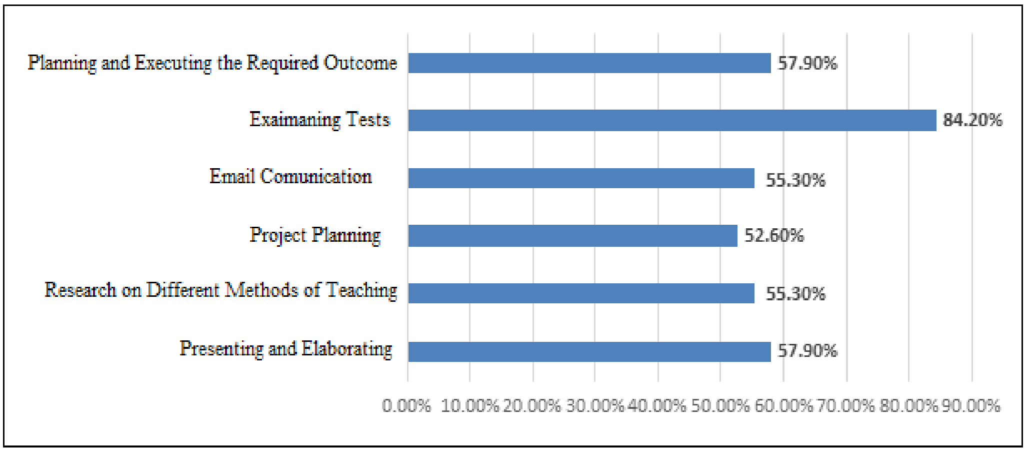
When asked which programs they use the most, the opportunity for answers has been open allowing options to be free of what respondents give. The programs they use most in their work are likely to be closely related to the trainings they have conducted in ICT. E - mail turns out to be with 25.6%, the program for managing Acces databases with 74.4%, the program for presentations Power Point 87.2%, Excel with 71.8% and Word 89.7%. High percentages are observed in this top five of application programs.



Graph 5. Which computer programs do you use?

Inclusion of ICT in Education

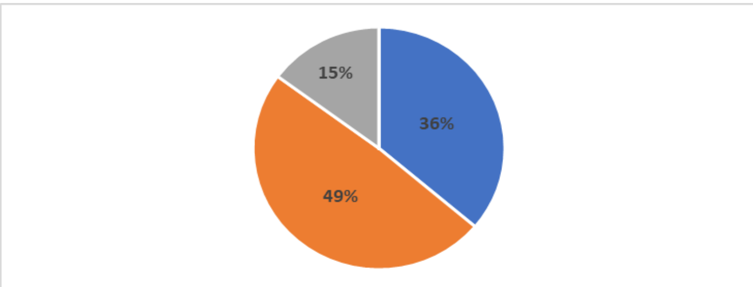
The opportunity to respond to the forms of how ICT is applied in the learning process has been open. Respondents were free to express the forms of how they apply ICT. In drafting plans and curricula and various exercises with 57.9%, drafting tests with 84.2%, for e-mail communication 55.3%, for drafting projects 52.6%, for research and to follow new methods in teaching field 55.3% and for illustration and presentations 57.9%,



Graph 6. How do you incorporate ICT into teaching?

Distribution of Electronic Materials, Exercises or Tasks

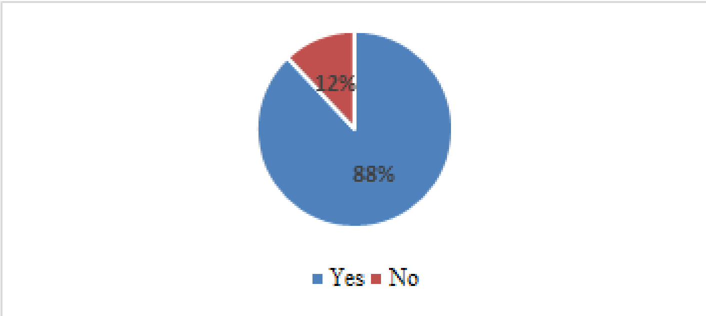
Among the ways that find the most use for the distribution of electronic materials is the orientation for internet use according to certain instructions with 49%, while the classic form of distribution of materials with CD or USB is present in the mass of 36% but also a modern form is noticed of creating groups or online forums where collaboration and exchange of materials and ideas is more efficient.



Graph 7. How you distribute electronic materials, exercises or assignments to students

IT Application Help or Complication?

When asked if the ICT application is a help to them, 88% of respondents said yes, it is a very big help and 12% of respondents said no, the ICT application is not a help to them.



Graph 8. Do you think that the application of IT has helped in your work?

Questionnaire Results with Students Attending School

This part of the research included 164 students from Kosovo of different ages. The focus of the questionnaire has been because young people are spending a lot of time online dealing with non-educational content about life in general. The following are the graphs with the respective results:

Computers in Schools

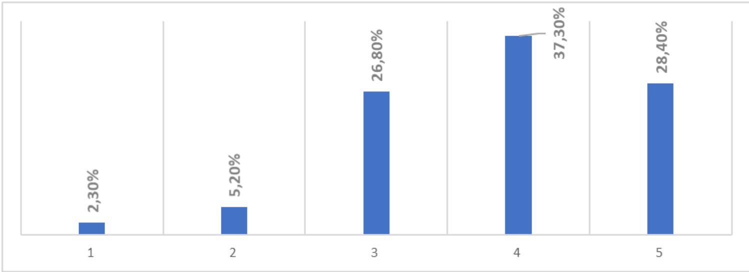
When asked if there is a computer in the school where you attend classes, 62.7% of the total respondent's state that they have computers while 37.3% state that they do not.

Graph 9. Do you have a computer in your school?

In the same question, teachers stated that approximately 61% of schools have computers. We can conclude that this is a real situation.

Computer Use

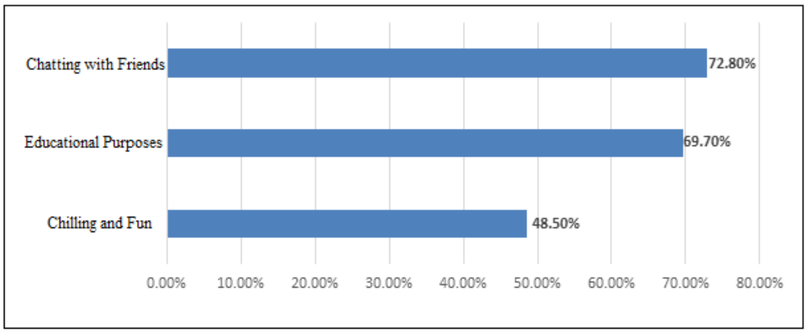
Asked about the level of knowledge for computer use, 37.3% rated themselves with level 4 out of a total of 5 levels that were, 28.4% stated 5, 26.8% stated 3, 5.2% rated themselves 2 and 2.3% with 1. We can freely say that we are dealing with a very good majority of computer users and a very small minority who have evaluated themselves poorly.



Graph 10. What is your level of knowledge about computer use in teaching, during the lesson with students?

Purpose of Use

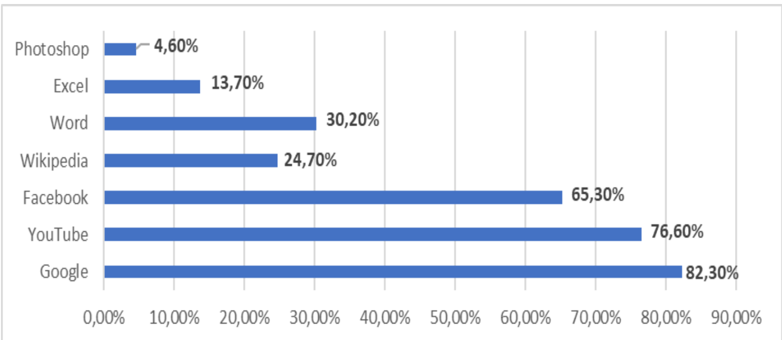
Addressing the correct use of this knowledge would be a great success. To a very large extent, 72.8% state that they mainly use it for conversations with friends on social networks, 69.7% for educational purposes and 48.5% mainly for entertainment.



Graph 11. For what purposes do you use information technologies

Programs Used

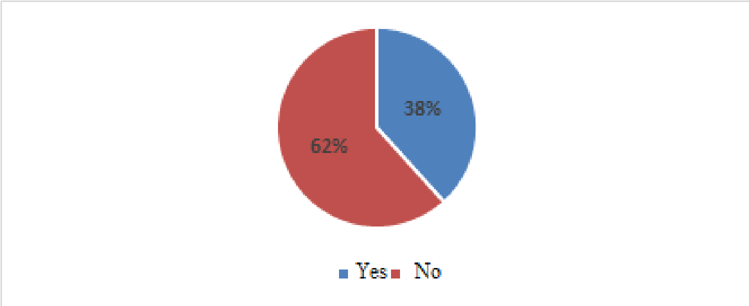
It was seen that the purpose of use may be different and to achieve their purpose users will use a certain instrument. An instrument can be a specific computer program. It is noticed that the target is Google which is used to the maximum through which they realize the desired access using it as a search engine. The question was open-ended and the respondents gave their options that created this graph:



Graph 12. Programs you use

IT Application

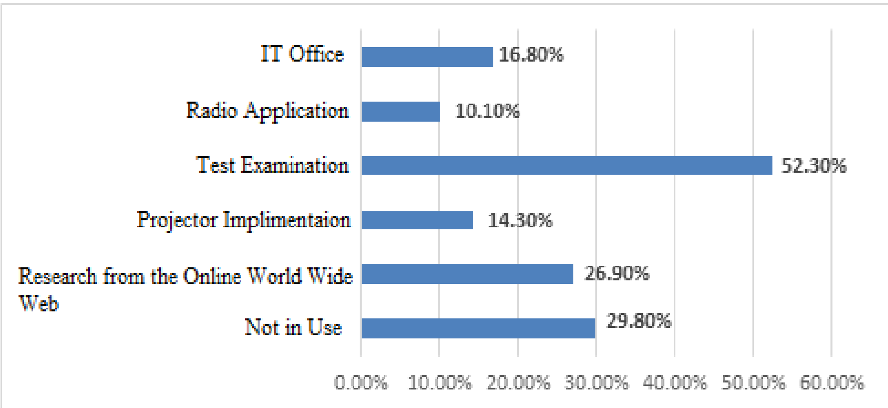
The inclusion of IT elements in the learning process, such as projectors or computers, does not seem to be satisfactory. A large proportion of 61.7% state that the teacher does not use teaching methods that include the use of the computer.



Graph 13. Does the teacher use teaching methods that include elements from IT

IT Integration Form

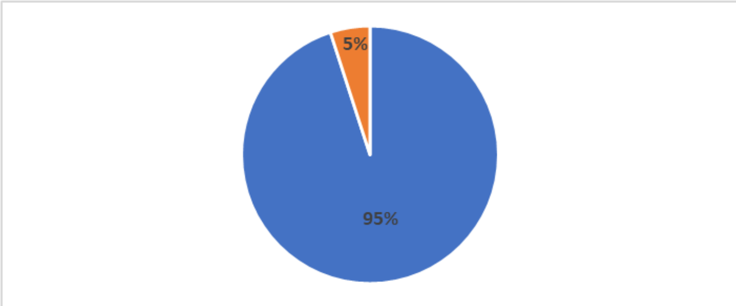
Methods for applying during the lesson can be different. Asked how teachers apply IT in the learning process, 29.8% stated that they do not apply it at all because they are not so clumsy in using the computer, 26.9% stated that the teacher guides them and seeks to bring research from the Internet, 14.3% apply the projector and 10.1% apply the radio



Graph 14. How teachers apply IT in the learning process

Application of IT Help or Complication, During the Lesson

IT application is seen as helping students, so at least 95% of them have stated.



Graph 15. Application of technology as support in work environments

Conclusions

Until nowadays, great progress has been made in the application of IT in educational institutions. This field has gained momentum over the last decade and has progressed rapidly. However, in order to further improve the situation, the process of drafting policies, strategic plans and taking concrete actions or measures within the application of IT, not only in the management of educational institutions, but also during the teaching processes and learning. At the same time, it is worth noting that further reform in this area is intended to be achieved through taking certain measures in different directions. These directions are within the ICT infrastructure in educational institutions, teacher training and qualification, development and standard setting, or application of best practices.

Taking further measures in the framework of improving the ICT infrastructure in the education system should focus on:

- increase of internet speed in educational institutions and quality of service;
- equipping teachers with laptops;
- equipping classrooms with projectors;
- equipment with output devices such as printers, speakers
- and other accompanying tools

Taking further measures in the framework of teacher training and qualification should focus on:

- trainings that should always be planned in accordance with the professional standards of teachers
- annual training planning
- Professional identification of professional needs.
- Training of teachers and managers of educational institutions

Need for training - Increasing and developing knowledge in the field of Technology would increase work efficiency.

The training will facilitate the transition from manual work with piles of papers in their offices to the way of electronic work, digitalized as well as in facilitating the use of applications, use of online service on the Internet, etc. User-level trainings would increase teacher's self-confidence in the work done as well as help and encourage the use of other applications necessary for working with students. The training would help them in their basic work, Computer. Training and certification in the ECDL Program would meet their needs.

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Using Writing Assessment to Evaluate the Children's Understanding of Moon Phase Changes

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Abstract: The purpose of this study is to explore the children's understanding of moon phase changes. Study methods include qualitative and quantitative methods. The subjects of the study are 683 students from grade three to six in an elementary school in New Taipei City. This study uses the method of writing assessment to explore the ideas of elementary school children on the causes of the moon phase changes and analyze the explanations of the causes of the moon phase changes. Students' writing assessment were collected as the major source for the study. In the analysis of the study data, first evaluate and classify the content and explanation of the causes of the moon phases by the schoolchildren, then conduct descriptive statistics to analyze the frequency distribution and percentage, and compare them according to the grade level. The writing assessment processes and the reliability and validity of the study were confirmed by three science educators and senior teachers. The results of the study found: (1) When students explain the causes of the moon phases of the full moon, waxing moon, last quarter moon, and first quarter moon during the day, the 3th graders mostly consider their own relationship, while the 4th, 5th, and 6th graders hold more views of the sun, moon, and the earth; (2) In terms of the proportion of students that the formation of moon phases is related to the sun, except that the proportion of last quarter moon in the 5th grade is slightly higher than that in the 6th grade, the rest are the highest in the 6th grade, indicating that the higher grade students feel the sun more related to the formation of the moon phases.

Keywords: earth science, Moon phases, Science learning, Writing assessment

Introduction

One of the learning points of the moon unit is to compare the moon phase changes with the lunar calendar date and understand the relationship between the moon phase changes and the lunar calendar date. This study tries to analyze the concept of the cause of the moon phases of the research object by discussing the relationship between the moon itself, the moon and the sun, the moon and the earth, the sun and the earth, the sun and the

Hsieh, T. D., Huang, S. J. (2021). Using writing assessment to evaluate the children's understanding of moon phase changes. In M. Shelley, W. Admiraal, & H. Akcay (Eds.), *Proceedings of ICEMST 2021-- International Conference on Education in Mathematics, Science and Technology* (pp. 50-57), Antalya, TURKEY. ISTES Organization.

moon and the earth, and others.

By analyzing the writing assessment results of the third to sixth grades of elementary school children on the causes of the moon phases of different moon phases, and longitudinally comparing the concept of the cause of the moon phases of the third to sixth grades of elementary school students, the purpose of this study is to explore the third to sixth grades children's perception of the moon is hoped to serve as a reference for the teaching of the moon phase unit in the future.

The questions to be answered are as follows:

1. What is the difference in explaining the causes of the full moon and the phases of the moon in the 3th to 6th grades of elementary school?
2. What is the difference between the explanation of the cause of the waxing moon phase by the students in grades 3 to 6 in elementary school?
3. What is the difference between the third to sixth grade students in elementary school explaining the causes of the last quarter moon phases?
4. What is the difference between the explanation of the causes of the first quarter moon phases by the children in grades 3 to 6 of elementary school?
5. What is the difference between the explanation of the relationship between the moon phases and the sun for the 3th to 6th grades of elementary school?

In the process of scientific inquiry, asking children to write down the sentences after thinking is one of the ways of inquiry. Champagne and Kouba (2005) believe that the content written by schoolchildren can be regarded as a kind of writing evaluation (Performance Measures, Performance Assessment). Writing assessment emphasizes that the context of the assessment should be real, showing the performance of children in a real situation, so writing assessment is a kind of authenticity assessment (Huang Shu-ling,1999). Shih-Jung, Huang et al. (2019) pointed out that in addition to emphasizing the connection with the content of the textbook and the evaluation in the real context, the writing evaluation also hopes to find an effective way to collect student data and reduce the time and funding constraints on research. In addition to using writing assessments to obtain students' conceptual situation of the causes of moon phases, this study also hopes to understand the perceptions of the moon in the 3th to 6th grades, so as to prepare for the follow-up study of longitudinal teaching design in the natural field.

Method

This research refers to the analysis models of Qiu Meihong, Chen Yingxian (1995) and Chen Cuiwen, Hou Yiling, and Liu Jiaru (2010), and try to discuss the relationship between the moon itself, the moon and the sun, the moon and the earth, the sun and the earth, the sun and the moon and the earth, and others. Analyze the concept of the cause of the moon phase of the research object.

Based on self-compiled writing assessments, 128 students in 3th grade in 5 classes, 398 students in 4th grade in 15 classes, 54 students in 5th grade in 2 classes, and 103 students in 6th grade in 4 classes. A total of 683 students explain the causes of specific moon phases. Analyze and classify. The writing assessment questions and analysis methods are set with the assistance of experts and senior teachers.

Results

In the writing assessment, students' personal thoughts on the causes of the moon phases are discussed. This study is divided into four lunar phases: full moon phase, waxing moon phase, last quarter moon phase, and first quarter moon phase. Statistics children are explaining the causes of moon phases. In the process, the moon itself, the moon and the sun, the moon and the earth, the sun and the earth, the sun and the moon and the earth, and others (own experience), explore the concepts and ideas of the 3th to 6th grade students in elementary school. The sub-items are as follows: Table 1 to 4.

Table 1. The discussion mode of the relationship between the 3th to 6th grades of elementary school students on the causes of the full moon phase

Grade/Mode	Moon	Sun and moon	Moon and earth	Sun and earth	Sun moon earth	other
3th	15 (11.72)	21 (16.41)	5 (3.91)	2 (1.56)	16 (12.50)	69 (53.91)
4th	18 (4.52)	79 (19.85)	17 (4.27)	2 (0.50)	136 (34.17)	146 (36.68)
5th	14 (25.93)	4 (7.41)	5 (9.26)	0 (0.00)	29 (53.70)	0 (0.00)
6th	31 (30.10)	13 (12.62)	7 (6.80)	1 (0.97)	47 (45.63)	3 (2.91)

It can be seen from Table 1 above that when students explain the causes of the full moon phases, the third-grade students have more opinions based on their own experience (53.91%) and the relative relationship between the moon and the sun (16.41%), and the fourth-grade students are The views on the relationship between the sun and the moon and the earth (36.68%), and the relative relationship between the moon and the sun (34.17%) accounted for the majority, while the fifth and sixth grade students are the sun, the moon and the earth (53.70%, 45.63%), The relative relationship of the moon itself (25.93%, 30.10%) is mostly.

Table 2. The discussion mode of the relationship between the 3th to 6th grades of elementary school students on the causes of the waxing moon phase

Grade/Mode	Moon	Sun and moon	Moon and earth	Sun and earth	Sun moon earth	other
3th	41 (32.03)	23 (17.97)	3 (2.34)	1 (0.78)	11 (8.59)	49 (38.28)
4th	25 (6.28)	83 (20.85)	15 (3.77)	0 (0.00)	113 (28.39)	162 (40.70)
5th	11 (20.37)	7 (12.96)	5 (9.26)	0 (0.00)	26 (48.15)	1 (1.85)
6th	41 (39.81)	14 (13.59)	6 (5.83)	1 (0.97)	38 (36.89)	1 (0.97)

It can be seen from Table 2 above that when students interpret the causes of the phases of the last quarter moon, the third-grade students are mostly based on their own experience (38.28%) and the moon itself (32.03%). The fourth-grade students are There are more opinions about their own experience (40.70%) and the relative relationship between the moon, the earth and the sun (28.39%). The fifth and sixth grade students are the relative relationship between the sun and the moon, the earth (48.15%, 36.89%), and the moon itself (20.37%, 39.81%) accounted for the majority.

Table 3. The discussion mode of the relationship between the 3th to 6th grades of elementary school students on the cause of the last quarter moon phase

Grade/Mode	Moon	Sun and moon	Moon and earth	Sun and earth	Sun moon earth	other
3th	31 (24.22)	29 (22.61)	2 (1.56)	0 (0.00)	5 (3.91)	61 (47.66)
4th	18 (4.52)	82 (20.60)	10 (2.51)	0 (0.00)	99 (24.87)	189 (47.49)
5th	7 (12.96)	7 (12.96)	5 (9.26)	1 (1.85)	31 (57.41)	0 (0.00)
6th	31 (30.10)	16 (15.53)	8 (7.77)	0 (0.00)	40 (38.80)	4 (3.89)

It can be seen from Table 3 above that when students explain the cause of the eyebrow-shaped crescent moon phase, the third grade students are based on their own experience (47.66%), the moon itself, and the factors of the sun and the moon (24.22%, 22.61%) Most of the views of the fourth grade students are about their own experience (47.49%), the relative relationship between the moon, the earth and the sun, and the relative relationship between the sun and the moon (24.87%, 20.60%). The fifth-grade children are the sun and the sun.

The relative relationship between the moon and the earth (57.41%) and the moon itself and the sun and the moon (12.96%, 12.96%) have more opinions. The order of the majority of sixth-grade students is the relative relationship between the sun and the moon and the earth (38.80%) and the moon itself. Relationship (30.10%) view.

Table 4. The discussion mode of the relationship between the 3th to 6th grades of elementary school students on the cause of the first quarter moon phase

Grade/Mode	Moon	Sun and moon	Moon and earth	Sun and earth	Sun moon earth	other
3th	3 (2.34)	36 (28.13)	1 (0.78)	0 (0.00)	3 (2.34)	85 (66.41)
4th	21 (5.28)	47 (11.81)	4 (1.01)	0 (0.00)	94 (23.62)	232 (58.29)
5th	6 (11.11)	9 (16.67)	2 (3.70)	2 (3.70)	29 (53.70)	1 (1.85)
6th	23 (22.33)	14 (13.59)	3 (2.91)	1 (0.97)	43 (41.75)	10 (9.71)

It can be seen from the above Table 4 that when students interpret the causes of the first quarter moon phases, the third-grade students are mostly based on their own experience (66.41%) and the relative relationship between the moon and the sun (28.13%). The fourth grade the order of most school children is based on their own experience (58.29%), the view of the sun and the moon and the earth (23.62%). The fifth grade school children are the relative relationship between the sun and the moon and the earth (53.70%), and the relative relationship between the moon and the sun (16.67%) There are more opinions on the relationship between the sun and the moon, the earth (41.75%), and the moon itself (22.33%) in the sixth grade.

The third-grade students are explaining the idea of the causes of the moon phases. This study found that most of the phenomena are based on their own experience, while the fourth to sixth grades shifted to more explanations based on the relationship between the sun, the moon and the earth. See four in astronomy studies after grades, students are better able to explain astronomical phenomena with the astronomical concepts and changes they have learned.

As for the relationship between the cause of the moon phase and the sun, the researcher gave the statistical answers and the results are shown in Table 5.

Table 5. Thoughts on the causes of the moon phases and the sun from the 3th to 6th grades of elementary school

Relationship / Grade	Have				No				Unanswered			
	Full moon	Waxing moon	Last quarter moon	First quarter moon	Full moon	Waxing moon	Last quarter moon	First quarter moon	Full moon	Waxing moon	Last quarter moon	First quarter moon
3th	65 (58.78)	39 (30.47)	46 (35.94)	45 (35.16)	22 (17.19)	33 (25.78)	28 (21.88)	29 (22.66)	41 (32.03)	56 (43.75)	54 (42.19)	54 (42.19)
4th	244 (61.31)	186 (46.73)	181 (45.48)	162 (40.70)	56 (14.07)	70 (17.59)	50 (12.56)	60 (15.08)	98 (24.62)	142 (35.68)	167 (41.96)	176 (44.22)
5th	33 (61.11)	32 (59.26)	32 (59.26)	28 (51.85)	2 (3.70)	6 (11.11)	7 (12.96)	5 (9.26)	19 (35.19)	16 (29.63)	15 (27.78)	21 (38.89)
6th	72 (69.90)	62 (60.19)	61 (59.22)	56 (54.37)	9 (8.74)	17 (16.50)	11 (10.68)	6 (5.83)	22 (21.36)	24 (23.30)	31 (30.10)	41 (39.81)

From Table 5 above, it can be seen that the proportion of schoolchildren that the formation of moon phases is related to the sun, except that the proportion of fifth grade (59.26%) in the last quarter of the moon is slightly higher than that of grade six (59.22%), the rest are all six. The highest grade, the higher the grade, the more I feel that the sun is more related to the formation of the moon phases.

Conclusion

We found students explain the causes of the moon phases of the full moon, the 3th grade students are based on their own experience and the views of the relationship between the moon and the sun, the 4th grade students are based on their own experience and the views of the relationship between the sun and the moon and the earth, the 5th grade students are based on their views on the relationship between the sun and the moon and the earth, and the moon itself. The 6th grade students are the view of the relative relationship between the sun and the moon and the earth, and the moon itself.

When school children interpret the causes of the phases of the waxing moon, the 3th grade students are based on their own experience and the views of the relationship between the moon itself, the 4th grade students are based on their views on the relationship between their own experience and the sun and the moon and the earth, the 5th grade students are based on their views on the relationship between the sun and the moon and the earth, and the moon itself. The 6th grade students are the view of the relative relationship between the moon itself and the sun and the moon and the earth.

We also found students explain the cause of the last quarter moon phase, the 3th grade students are based on their own experience and the views of the relationship between the moon itself, the 4th grade students are based on their views on the relationship between their own experience and the sun and the moon and the earth, the 5th grade students are based on their views on the relationship between the sun and the moon and the earth, and their own experience. The 6th grade students are the view of the relative relationship between the sun and the moon and the earth, and the moon itself.

When students interpret the causes of the first quarter moon phases during the day, the 3th grade students are based on their own experience and the views of the relationship between the sun and the moon, the 4th grade students are based on their views on the relationship between their own experience and the sun and the moon and the earth, the 5th grade students are based on their views on the relationship between the sun and the moon and the earth, and the sun and the moon. The 6th grade students are the view of the relative relationship between the sun and the moon and the earth, and the moon itself.

In terms of the proportion of school children that the formation of moon phases is related to the sun, except that the proportion of last quarter in the 5th grade is slightly higher than that of the 6th grade, the rest are the highest in the 6th grade. The higher the grade, the more relevant the formation of the sun and the moon phase is.

Recommendations

The results of the writing assessment of the schoolchildren can be seen in the schoolchildren's concept of the cause of the moon phase. After the 4th grade study of the moon unit, there are still many incomplete or other concepts, so how to effectively change the teaching method to help the schoolchildren change Their concept needs further research.

This study initially explores the thinking mode of the causes of the moon phases in the 3th to 6th grades. In the future, it can analyze the concept of the content of the students' answers to obtain more information and provide research on how to effectively change the teaching method to assist School children change their other concepts.

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A Study on Using Matrix Laser Teaching Aids to Improve the Learning Effectiveness of Elementary School Students on the Moon Observation Unit

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Abstract: The purpose of this study is to use the matrix laser teaching aids to teach in the moon observation unit to explore the effectiveness of science learning of elementary school students. The subjects of the study were 367 fourth-grade students in an elementary school in New Taipei City, including 154 students in the experimental group and 213 students in the control group. In this study, we first designed a matrix laser teaching aids to produce parallel light like the sun, so as to provide moon observation unit for teaching, which can show the true changes of moon phase changes in teaching. Students in the experimental group received the instruction with the matrix laser teaching aids on the moon observation unit, while students in the control group received the conventional instruction. The research instrument is the Moon Observation Unit Achievement Test, and the reliability of the test is Cronbach α=.72. The analysis of research data adopts covariate analysis. The results of the study found: (1) There is no significant difference between the experimental group and the control group in the learning effects on the concepts of the moon; (2) The experimental group did better than the control group on the understanding of observing the moon ($F=10.211$, $p<.01$); (3) The experimental group did better than the control group on the understanding of moon phase changes ($F=10.220$, $p<.01$).Therefore, it can be concluded that using matrix laser teaching aids is effectiveness for the moon observation unit in this study.

Keywords: Matrix laser light teaching aids, Moon phases, Science learning

Introduction

Autumn is the best time to observe the moon. This is exactly how elementary school teach this unit between September and October every year. From the first quarter to the last quarter of the moon, you can discover the surface of the moon. There are obvious differences in light and dark. We call this phenomenon the moon-phase

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observation of the moon. If you use the long-term observation method of scientific process skills and the continuous spirit of patience and perseverance, you can detect the moon's phase in the observation records. There are rules for profit and loss changes. School children often have many other concepts in the learning and cognition of the moon unit. It is worthwhile to further explore the improvement of teaching materials at the level of teaching materials.

The purpose of this research is to explore whether the matrix laser teaching can improve the cognitive learning of the moon phase changes in the learning of the moon observation unit for middle-grade students in elementary schools.

The questions to be answered are as follows:

1. What is the difference between the learning effectiveness of moon cognition for students receiving matrix laser teaching and the students receiving general traditional teaching?
2. What is the difference between the learning effectiveness of observing the moon cognition for students receiving matrix laser teaching and the students receiving general traditional teaching?
3. What is the difference between the learning effectiveness of the moon phase change cognition for the students receiving the matrix laser light teaching and the students receiving the general traditional teaching?
4. Does the matrix laser light teaching aid help to improve the learning effectiveness of the students' cognition of moon phase changes?

The study of moon phase changes has always been a problem for elementary school students. Because of the movement of celestial bodies, school children have not been able to experience it. The main reason for school children's inability to express the surplus or lack of moon phases is that they cannot observe the overall structure of the sun, moon, and earth environment from a single point of view of moon phase changes and their interactions (Helm and Novak, 1983). Therefore, in the element of elementary school's nature and life science and technology in the middle-grade moon observation unit, students often have various myths or other concepts about the moon phase, especially the parallel light effects and experiments related to the sun's rays hitting the earth from a long distance.

There is no specific inquiry discussion (Wang, Mei-Fun, 1992; Jiang, Fan, 1993; Driver., Asoko, Leach, Mortimer and Scott, 1994; Xu, Ming-Yan and Wang, Ching-Kun, 2001). This is probably because the simulation environment of many teaching experiments is in general. A light bulb or flashlight replaces the sun, but the light source diverging from the light bulb to the surroundings cannot correctly express the concept of parallel light (Su, Wei-Zhao, 2007); when the light from the bulb hits the sphere, the gradual brightness of the reflective surface is not easy to outline the clear appearance of the moon , There is a big gap between the phases of the moon and the actual observations. Therefore, how to instruct students to understand the correct concept of sunlight and phases of the moon in teaching activities has always troubled the teaching of teachers in the field of nature.

The matrix laser light teaching aid gives a new opportunity for the moon unit to learn. Due to personal experience simulating the parallel laser light of the sun, students can find that the change of the moon phase is caused by an infinite number of parallel sun lights shining on the surface of the moon. Traditional light bulbs or the flashlight can only project a collective beam, and it is impossible for students to observe the parallel light of the sun on weekdays and the moon phase seen at night, and they cannot understand the parallel characteristics and influence of sunlight.

The laser parallel light matrix allows students to clearly know that the sun is shining on the moon in the form of parallel light, and they can learn about the mystery of the moon phase change in the follow-up study of the rotation and revolution of the moon and the earth. The matrix laser light teaching aid can correctly express the concept of solar parallel light, and the research results can also significantly improve the learning effectiveness of the students' ability to observe the moon phases and the recognition of moon phase changes, providing teachers with a better choice for teaching the moon phase unit.

Method

The object of this research is 367 students in the fourth grade of a elementary school in New Taipei City. A total of 14 moon phase units are taught. The experimental group includes 154 students in six classes, and the control group includes 213 students in eight classes. The experimental group accepts the integration of matrix lightning. In the light teaching, the control group was taught in general traditional style. Both groups received the moon phase unit cognitive achievement test before and after the teaching, and then conducted independent sample covariate analysis based on the pre- and post-test data between the two groups.

This study uses the Kang Hsuan version of the fourth-grade moon unit textbook, which is mainly divided into three learning activities: moon cognition, observation of the moon and moon phase changes. Among them, the matrix laser parallel light teaching aid is mainly used in the cognitive teaching of moon phase changes, and the sun is set to be parallel. The experimental field of light allows students to experience the changes of the moon phases (Kang Xuan Wen Jiao, 2018). In the learning activities of the moon phase changes, the content of the teaching materials are mainly about how the moon phases change from 3-1 to 3-1.

It is mainly hoped that through life experience, students can tell that the moon phases they see on different dates are different, and through learning, they will observe and record for a long time. Moon phase changes; 3-2 Moon Phase Observation Diary, allowing students to observe the moon’s long-term activities to detect the regularity of the moon phase changes and the relationship between the moon phase changes and the lunar calendar date, and learn to predict from the lunar calendar date Moon phases; the regularity of moon phase changes from 3 to 3 allows school children to learn and understand the relationship between the traditional Chinese calendar (lunar date) and moon phase changes by summarizing the moon phase changes in a month.

The researcher used 110 red lasers arranged in an 11*10 matrix, fixed on a wooden frame, matched with a smoke generator, and projected the laser light (simulating the sun) on the simulation of the moon (white Styrofoam ball). The light appeared. In the regular teaching activities of 3-3 moon phase changes, after students have a preliminary understanding and understanding of the moon phases, the experimental group will be taught matrix laser light. During the process, the changes of the moon phases will be reviewed and the students will be guided to understand the sun. The relationship between the distance and the distance of the moon from the earth, let students observe the white Styrofoam ball (simulating the moon) illuminated by laser light (simulating the sun), understand the changes of the moon phases such as the first quarter moon, full moon, and last quarter moon, and perceive the moon phases The change is caused by the sun's rays in different positions of the moon.

In this research, a matrix laser parallel light teaching aid that simulates the sun is made, and with a smoke generator, this matrix laser parallel light can actually show the effect of simulating the sun’s parallel light in the teaching experiment, and the matrix laser parallel to the sun will be simulated. The light shines on the white Styrofoam balls that simulate the moon in different corresponding positions in the teaching site, and the teaching plan and unit activity design of the moon unit developed by the researcher are used for teaching. The content of the cognitive achievement test questions has passed the internal consistency letter. For degree analysis, the measured Cronbach α value is .724, and the estimated reliability coefficients of all items in the overall statistical analysis of the project are mostly consistent, which are used as pre- and post-tests. Then carry out experimental teaching and general standard teaching, and compare the learning effects of students.

Results

Students who receive matrix laser light teaching have no difference in the learning effect of moon cognition from students who receive general traditional teaching.($p=.900$, $p>.05$) Students who receive matrix laser light teaching have better learning results in observing moon cognition than students who receive general traditional teaching ($p=.002$, $p<.05$) Matrix laser light teaching can help improve students' learning effectiveness in observing moon cognition. Students who receive matrix laser light teaching have better learning results than students who receive general traditional teaching ($p=.002$, $p<.05$) Matrix laser light teaching can help improve students' learning results in the understanding of moon phase changes.

Table 1. Covariate analysis results of independent samples of cognitive achievement test between experimental group and control group

Source	The cause variable	Type III Sum of Squares	df	Average square	F	Sig.
Modifying the model	Activity 1 post-test	2.116	2	1.058	3.429	.033*
	Activity 2 post-test	23.329	2	11.665	9.704	.000**
	Activity 3 post-test	91.099	2	45.550	7.026	.001**
intercept	Activity 1 post-test	163.553	1	163.553	530.086	.000**
	Activity 2 post-test	637.290	1	637.290	530.154	.000**
	Activity 3 post-test	3851.124	1	3851.124	594.032	.000**
Activity 1 pre-test	Activity 1 post-test	2.114	1	2.114	6.851	.009*
	Activity 2 post-test	5.071	1	5.071	4.201	.041*
	Activity 3 post-test	21.710	1	21.710	3.354	.068
Activity 2 pre-test	Activity 1 post-test	.114	1	.114	.364	.547
	Activity 2 post-test	6.931	1	6.931	5.766	.017*
	Activity 3 post-test	5.580	1	5.580	.856	.355
Activity 3 pre-test	Activity 1 post-test	.000	1	.000	.001	.974
	Activity 2 post-test	12.769	1	12.769	10.766	.001**
	Activity 3 post-test	18.313	1	18.313	2.825	.094
Constituencies	Activity 1 post-test	.005	1	.005	.016	.900
	Activity 2 post-test	12.274	1	12.274	10.211	.002*
	Activity 3 post-test	66.257	1	66.257	10.220	.002*
Error	Activity 1 post-test	112.309	364	.309		
	Activity 2 post-test	437.559	364	1.202		
	Activity 3 post-test	2359.816	364	6.483		
grand total	Activity 1 post-test	2710.000	367			
	Activity 2 post-test	8701.000	367			
	Activity 3 post-test	6981.000	367			
Corrected Total	Activity 1 post-test	114.425	366			
	Activity 2 post-test	460.888	366			
	Activity 3 post-test	2450.916	366			

**=p<.01, *=p<.05

Conclusion

We can find that there is no difference in the learning effectiveness of moon cognition for students who receive matrix laser teaching and students who receive general traditional teaching. The students who receive the matrix laser teaching are more effective in observing the moon than the students who receive the general traditional teaching. The learning effect of the students who received the matrix laser light teaching is better than the students receiving the general traditional teaching. It can be seen that the matrix laser light teaching helps to improve the learning effect of the students in observing the moon and moon phase change cognition.

The matrix laser light teaching does help students understand how the sun's long-distance parallel rays affect the moon through actual observations. By clearly delineating the outer periphery of the moon phase, students can understand the cause of the moon phase change due to the earth. The relationship between the relative positions of the moon, the moon and the sun further assist students in obtaining the correct scientific concepts of the moon phases, making the teaching of the moon unit produce meaningful learning effects.

Recommendations

This study suggests that future studies can continuously improve the density of matrix laser light, so that the image of moon phase changes can be more clearly outlined, and if this study can have more empirical research, we believe that more understanding of the benefits of matrix laser light teaching.

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A Review of Theses and Dissertations Published in Turkey on Early Geometry Skills in 2000-2020

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Abstract: This study was carried out to review the theses and dissertations on early geometry skills published in Turkey. In the study, which was organized as a methodological evaluation study, the data were obtained through document analysis method. The research is limited to 20 studies, published between 2000-2020, of which full texts could be accessed from the Turkish National Thesis Center database. The full texts of the theses and dissertations were accessed by using the keywords "geometry in preschool period", "early childhood geometry", "early geometry skills", and "geometric shape". The data obtained within the scope of the research were analyzed and discussed according to the publication year of scientific studies, language, university, research design, research method, subject, and sampling type. When the documents were analyzed, it was seen that most of the thesis studies were master's theses, mainly belonging to the year 2010 and after, and all of the doctoral dissertations belonged to 2011 and later. It has been determined that the language of the majority of the theses was Turkish, mostly from Selçuk University and Gazi University and conducted following quantitative methods.

Keywords: Early geometry skills, Geometry, Pre-school

Introduction

Since ancient times, human beings have made mathematics a part of their lives in the face of situations involving mathematical skills such as numbers, shapes, counting system, and grouping. For example, they used numbers to share a property, they thought that whatever form they used in building a house would get better results, they started to use mathematical operations in harvesting and shopping. This requirement has caused the fields of mathematics to change over time and the development of mathematics research. Instead of counting with a finger, numbers began to be used in higher-level operations, and even the abacus and then various technological machines were developed. In time, it was determined that geometry does not only consist of

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shapes, but also includes the definition of the area inhabited, the relationship between shape and area. With the changes in the fields in which mathematics is used, the research on mathematics diversified and the importance and difference of mathematics teaching for each education level was determined. In particular, the importance of developing mathematics skills in early childhood has been demonstrated (Clemson & Clemson, 2001). One of the mathematical skills that started to develop through the curiosity and natural experiences of children in this period is expressed as early geometry skill (Clements & Sarama, 2009).

According to Copley (2000), geometry, which includes shapes, size, position, direction and movement, is a sub-field of mathematics and defines and classifies the world we live in. Clements and Battista (1992) expressed geometry as *"the study of the spatial properties, relations and transformations of objects in space."* Geometry is generally concerned with establishing certain relationships through thinking and reasoning. Generally, although geometry is called shape and area, it also includes points, lines, planes, and other two-dimensional and three-dimensional shapes (Cooke, 2007). Understanding the concepts that are considered as building blocks of geometry such as point, line, plane, angle is important because they are used in various applications (Chapin & Johnson, 2006).

It allows children to understand geometric concepts and gain skills related to geometry, to analyze and interpret the world they live in (Özerem, 2012). Geometry, which is the study of space and shape, is important because it forms the basis of learning most of the mathematics and other subjects (Clements, 1998). Children's relationships with geometry begin in infancy and gradually increase. A toddler discovers the space, directs his / her movements, learns to orient himself / herself in space. This awareness, which starts with the bodies first, continues to increase in time with the positions of the objects, the distance between them, the movements under, above, inside and outside of the objects (Schwartz, 2005). Children who discover that everything around them has a shape, begin to distinguish shapes three weeks after they are born (Kesicioğlu, Alisinanoğlu, & Tuncer, 2011). When children begin to see similarities and differences in shapes, they become aware of geometric forms. While the spherical properties of three-dimensional objects draw their attention, they then distinguish three-dimensional shapes such as cones, cubes, cylinders, and two-dimensional shapes such as rectangles, triangles, squares and circles (Schwartz, 2005). At the same time, children interpret the physical world with geometric ideas and make use of the geometric vocabulary they have created in recognizing and naming shapes such as square, triangle, circle, rectangle, hexagon, sphere, and cube that exist around them (Clements & Sarama, 2009). For this reason, qualified educational environments and processes should be planned and implemented in order for children to learn geometric shapes, especially in the early period (Clements & Sarama, 2009).

Geometry skills should be supported by various activities from an early age in order to establish a strong foundation of geometry in children (Clements & Sarama, 2004). Climbing, swinging, sliding, block, building, lego and manipulative tabletop games should be preferred frequently in the preschool period in order to improve the spatial abilities of children (Smith, 2006). At the same time, it is very important to ensure that children use words related to the spatial field in games and activities during the day. Spatial field words, which are location, location words, motion words, distance words and transformation words, contribute significantly to the development of spatial perception of children (Copley, 2000). Children learn geometry as they connect with the objects and shapes, they see and interact with. For example, as children are exposed to geometric shapes and repeat their names, the name of the geometric shape is connected to each other in time (Schwartz, 2005). It is important for children to encounter concrete materials for learning the geometric shape in the preschool period. For example, in the learning of the square shape, concrete materials can be given, and the similarities and differences can be determined by comparing the features such as the number of sides and the length of the sides according to the shapes such as rectangles, triangles and circles. In addition, while the child is learning the shapes, he / she may be asked to present the forms of the same shape with different position, skewness and flatness to the child and make a comparison (Aktaş Arnas & Aslan, 2005). Teachers should take advantage of children's curiosity and do purposeful and qualified activities related to early geometry skills. Being aware that every child has a different level of geometry knowledge, examples of various geometric shapes should be presented in the classroom, children should be provided with geometric shapes, and activities related to the spatial field should be carried out to develop the spatial thinking of children (Jung & Conderman, 2017).

Researchers have carried out studies in Turkey in order to investigate how to support early geometry skills and stated the importance of this skill. Accordingly, Kesicioğlu, Alisinanoğlu, and Tuncer (2011) found that preschool children made mistakes in recognizing triangle, square, rectangular, circle shapes and their distractors in the study that examined their level of recognition of geometric shapes. Turan Topal (2010) suggested that preschoolers have difficulties in associating and distinguishing geometric shapes from similar features, and although they are quite successful in recognizing typical examples of shapes, they have difficulty recognizing shapes when the kurtosis, skewness, position and size or edge features of typical examples are changed. Hacısalihoğlu Karadeniz (2014) determined that children in the mathematics education process, when supported with appropriate and rich activities, can apply the instructions regarding location and spatial relations in the map samples. Sezer (2015) stated that the variables of age and parents' education level made a difference on children's geometry skills, children aged 5-7 years had no problem in distinguishing typical (prototype) examples of shapes, but they were affected by atypical and invalid examples of shapes in shape selection. Korkmaz (2017) determined that inquiry-based mathematics activities applied in natural open spaces can be used as an effective tool to support the development of geometric and spatial thinking skills of 48-66-month-old children. Kılıç (2018) applied the Preschool Geometry Education Program (PGEP) to the children in the experimental group three days a week for 10 weeks and concluded that there was a statistically significant difference between the children in the experimental group participating in PGEP and the children in the control group, in favor of the children in the experimental group. Keser (2020) found that children's attention skills significantly predicted their early geometry skills, and that there was a positive and moderately significant relationship between children's phonological awareness skills and early geometry skills. Besides, between parents' education level and children's geometry skills and phonological awareness skills, it has been concluded that the relationship for the parents whose education level was middle school and below, high school and university were positively and moderately, and in the group whose parents have graduate education level were positively and at a high level.

According to the relevant literature, it has been revealed that children's early geometry skills differ according to variables in early childhood, when brain development is very fast, and educational environments and different educational programs affect the development of early geometry skills. Relevant research results may contribute to a better understanding of the importance of early geometry skills and the development of their place in educational programs. However, the literature review conducted in Turkey related to early geometry skills shows that a limited number of master's theses and doctoral dissertations have been published so far. Therefore, this research is important in terms of shedding light on this gap in the related literature. Analyzing scientific theses and dissertations can provide information about the depth and extent of that topic and reveal the general view of the area studied. In this context, this study, which aims to review the master's theses and doctoral thesis prepared in universities in Turkey related to early geometry skills, is expected to give information about the general trend and the research methods while inspiring the specialists and contributing to the literature. Hence, this research was carried out to review theses and dissertations published in Turkey on early geometry skills in 2000-2020. For this purpose, answers to the following questions were sought:

1. What is the distribution of theses and dissertations on geometry in preschool period according to years?
2. What is the distribution of studies on geometry in preschool period according to the language in which it was published?
3. What is the distribution according to the universities where the master's theses on geometry in preschool period were published, the method used and the study groups?
4. What is the distribution according to the universities where doctoral dissertations on geometry in preschool period were published, the method used and the study groups?
5. What is the distribution of theses on geometry in preschool period by subject?
6. What is the distribution of studies on geometry in preschool period by sampling method?

Method

Research Design

This research which aims to review the theses and dissertations on early geometry skills development and evaluation in Turkey was conducted by qualitative method. Document analysis was used in the research conducted with the descriptive scanning model. Qualitative model is a method that aims to examine the subject in depth (Karataş, 2015). Document is any material that provides information on social facts and exists independently of the researcher (Corbetta, 2003). Document analysis includes the analysis of written materials that contain information about the events and facts that are aimed to be investigated (Şimşek, 2009) and enables the analysis of documents produced in a certain time frame about a research problem based on a long time period (Yıldırım & Şimşek, 2011).

Population and Sampling

Since the aim of the study was to review the theses and dissertations on geometry skill in the preschool period, the population of the research consisted of theses and dissertations, published between 2000-2020, of which full texts could be accessed online from the database of the Turkish Higher Education Council National Theses Archive. No sampling method was used in the study as the researchers aimed to reach the whole population. Thus, a total number of 20 theses and dissertations on the topic were reviewed.

Data Collection and Analysis

In the study, master's theses and doctoral dissertations on early geometry skills covering the years 2000-2020 and available online in January-February were downloaded and used as documents.

In the first stage of document analysis, the full texts of the theses and dissertations in the study group were accessed from the database. The keywords "geometry in preschool period", "early childhood geometry", "early geometry skills", "geometric shape", "mathematical concepts" were searched in Turkish and English from the database. The selection criteria of of the theses and dissertations listed online were as follows:

a. Theses were between the years 2000-2020.
b. Focusing on geometry in early childhood, pre-school education or the geometry skill of preschool teachers.
c. One of the scales used in the thesis or the dissertation was about early geometry skill.
d. Early geometry skill not being evaluated within the scope of the same measurement tool as other mathematical skills.

Theses or dissertations which did not comply with the above-mentioned criteria in the database of the Turkish National Thesis Archive were not evaluated. Accordingly, 15 master's theses and 5 doctoral dissertations on early geometry skills were examined in this research.

The documents included in the study were selected in accordance with certain criteria determined by Scott (1990). In this sense, Scott (1990) suggested that the validity and reliability of the documents should be evaluated according to the criteria of (1) the fact that the document is authentic, (2) it is believable to include its accuracy, (3) it is far from imitation, (4) it contains current meaning. Detailed examinations were carried out by the researchers to determine the compliance of the documents with the criteria.

In order to ensure validity in qualitative research, it is necessary to report the data in detail and explain the ways to reach the results (Yıldırım, 2010). In this study, it was aimed to present the data research process and the reported data in detail in order to ensure validity. In order to ensure the reliability of the study, the collected data were analyzed separately by the researchers, and then compared, synthesized, and reported.

Master's theses and doctoral dissertations included in the research were collected by taking into account the five stages of document review (Şimşek, 2009):

1. In the first step of *accessing the documents*, the documents needed and the keywords to access these documents were determined. Accordingly, the documents needed in the research were obtained with the keywords from the National Theses Archive of the Turkish Council of Higher Education. The determined documents were filed in pdf format and saved to the computer.
2. *In checking the originality*, the documents were accepted as original since the researchers accessed the data from the National Thesis Archive of Turkish Higher Education Council.
3. The theses and dissertations to be included in the research at the stage of *examining and understanding the documents* were done by the researchers. The accessed theses, in line with the aims of the research; were classified in terms of type, year of publication, language, university, to whom it is intended, subject, research design, sampling type, and data collection tools.
4. Descriptive statistics were included in the *analysis of the data*. Descriptive statistics were conducted in terms of factors such as the frequency and percentage used in themes such as the status of master's thesis, doctoral dissertation being published as an article, publication year, language, subject, sampling method of included in the scope of the research (Arıkan, 2011; Yıldırım & Şimşek, 2011).
5. *The use of data* is the last step of document review. At this stage, the findings of the research were analyzed and interpreted by the researchers. Information and recommendations that were expected to shed light on the literature were included.

Findings and Discussion

In this part of the study, the findings regarding the theses and dissertations on geometry skills in the preschool period are presented and discussed in line with the sub-objectives of the research.

1. What is the distribution of theses and dissertations on geometry in preschool period according to years?

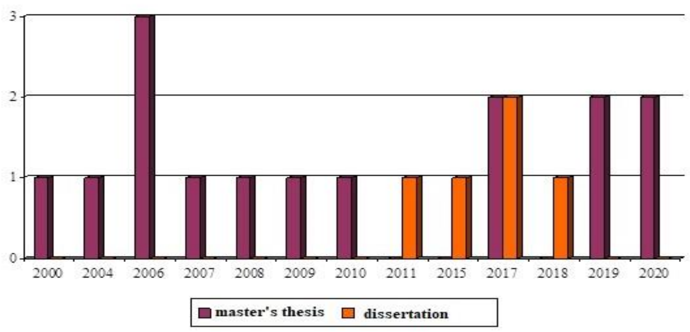

Figure 1. Distribution of studies on geometry in the preschool period by years

According to Figure 1, when the distribution of theses and dissertations included in the scope of the research by years was considered, there were 1 master's thesis in 2000 and 2004, 3 master's theses in 2006, 1 master's thesis in 2007, 2008, 2009, 2010, and 1 doctoral dissertation in 2011 and 2015. In 2017 there were, 2 master's theses, 2 doctoral dissertations, 1 dissertation in 2018 and 2 master's theses in 2019-2020. According to this, it was seen that 60% of the master's theses were made in 2010 and after, and all doctoral dissertations were made in 2011 and after. The most thesis studies were done in 2017 with a rate of 20%. Considering the given numbers, it can be said that thesis and dissertation studies on geometry in preschool period have increased in recent years. In this case, it can be thought that researchers' interest in studying early geometry skills has increased.

2. What is the distribution of studies on geometry in preschool period according to the language in which it was published?

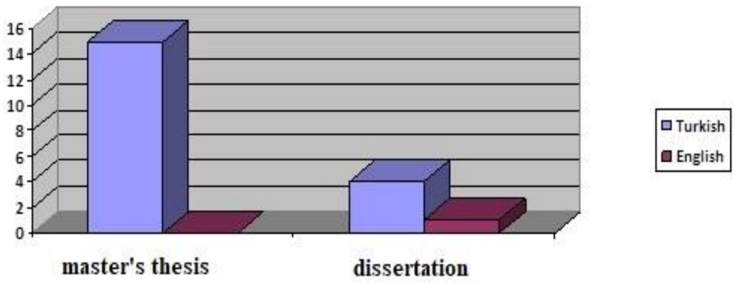

Figure 2. Distribution of studies on geometry in preschool period by language

In line with the findings shown in Figure 2, when the distribution of the studies included in the study according to the language in which they were published is examined, it was found out that the majority of them are Turkish. It is noteworthy that while all of the master's theses were in Turkish, only 20% (n = 1) of the doctoral theses were in English.

3. What is the distribution according to the universities where the master's theses on geometry in preschool period were published, the method used and the study groups?

Table 1. Distribution of the master's theses on geometry in the preschool period according to the universities where they were published, the method used and the study group

Title	University / City	Design	Study Group	Year
Comparison of structured and traditional methods in teaching some mathematical concepts to 6-year-old children who attend preschool education institutions	Gazi University Institute of Social Sciences, Ankara	Quantitative	Pre-school period	2000
Investigation of 3-6 age group children attending kindergarten to recognize basic geometric shapes and the criteria they use to distinguish shapes	Çukurova University, Institute of Social Sciences Department of Early Childhood Education, Adana	Qualitative	Pre-school period	2004

Comparative examination of structured and traditional methods in order to teach some mathematical concepts to six-year-old children attending preschool education institutions	Selçuk University Institute of Social Sciences Department of Child Development and Domestic Management, Konya	Quantitative	Pre-school period	2006
Teaching computer-aided mathematical concepts to six-year-old preschool children	Selçuk University, Institute of Social Sciences, Konya	Quantitative	Pre-school period	2006
The role of computer-aided education in preschool education	Gazi University, Institute of Natural and Applied Sciences, Ankara	Quantitative	Pre-school period	2006
The effect of concept education program on the development of geometric shape and number concepts of 6-year-old children	Adnan Menderes University, Institute of Social Sciences Department of Elementary Education, Aydın	Quantitative	Pre-school period	2007
The effectiveness of the Montessori education method in giving the concept of geometric shape to 4-5 age group children attending preschool education institutions	Selçuk University Institute of Social Sciences Department of Child Development and Domestic Management, Konya	Quantitative	Pre-school period	2008
The effect of drama method on the development of mathematical shape perception and number concept in children aged 5-6	Selçuk University Institute of Social Sciences Department of Early Childhood Education, Konya	Quantitative	Pre-school period	2009
How do preschool children perceive the concepts of geometry being taught?	Gazi University Institute of Educational Sciences, Department of Mathematics Education, Ankara	Qualitative	Pre-school period	2010
Investigation of the effect of mathematics education given to 6-year-old children with narrative method on children's mathematics achievement	Dumlupınar University Institute of Educational Sciences Department of Early Childhood Education, Kütahya	Mixed	Pre-school period	2017

The effects of Froebel gifts on the geometry skills of 60-72-month-old children attending pre-school education institution	Okan University Institute of Social Sciences Department of Early Childhood Education, İstanbul	Quantitative	Pre-school period	2017
Examination of visual perception skills and geometry skills of pre-school children	Trakya University Institute of Social Sciences Department of Early Childhood Education, Edirne	Quantitative	Pre-school period	2019
Investigation of the relationship between 60-72-month-old children's learning center preferences and geometry skills	Bolu Abant İzzet Baysal University Institute of Educational Sciences Department of Early Childhood Education, Bolu	Quantitative	Pre-school period	2019
Investigation of pre-school children's executive function skills and geometric shape perceptions	Hacettepe University Institute of Educational Department of Early Childhood Education, Ankara	Mixed	Pre-school period	2020
Investigation of the relationship between 60-72-month-old children's attention skills and geometry and phonological awareness skills (Afyonkarahisar province sample)	Afyon Kocatepe University Institute of Social Sciences Department of Educational Sciences, Afyon	Quantitative	Pre-school period	2020

As shown in Table 1, there were 15 master’s theses which investigated early geometry skills in pre-school period. No master's theses were found in the search of the databases with the keywords "geometry in preschool period" and "geometry in early childhood". 3 master theses were found in the search with the keyword "early geometry skills" while 10 master theses in the search with the keyword "geometric shape", and 2 master theses in the search with the keyword "mathematical concepts" were accessible (Dere, 2000; Aslan, 2004; Kırlar, 2006; Alabay, 2006; Kacar, 2006; Aydoğan Akuysal, 2007; Öngören, 2008; Yalım, 2009; Turan Topal, 2010; Şen, 2017; Sertsöz, 2017; Kurt, 2019; Aydın, 2019; Öğütcen , 2020, Keser, 2020).

It was seen that the master’s theses included in this study were prepared under 10 different universities. It was determined that 26.66% (n = 4) of the theses originated from Selçuklu University and 20% (n = 3) from Gazi University. It can be said that Selcuk University and Gazi University contributed to this field with a higher number of master’s theses. When the methods of master's theses were examined, it was determined that 11 studies were carried out quantitatively, 2 studies were conducted with qualitative research, and 2 studies were conducted with mixed design. It was found out that all of the master's theses on geometry included pre-school children in their study group.

4. What is the distribution according to the universities where doctoral dissertations on geometry in preschool period were published, the method used and the study groups?

Table 2. Distribution of doctoral dissertations on geometry in preschool period according to the universities where they were published, the method used and the study group

Title	University / City	Design	Study Group	Year
Investigation of the effect of the education program prepared by direct instruction method and the computer-aided education program prepared according to this method on preschool children's learning the concepts of geometric shape	Gazi University, Institute of Educational Sciences, Department of Early Childhood Education, Ankara	Quantitative	Pre-school period	2011
Developing early geometry skill test and examining children's geometry skills	Marmara University Institute of Educational Sciences, Department of Early Childhood Education, İstanbul	Quantitative	Pre-school period	2015
Augmented reality activities for children: a comparative analysis on understanding geometric shapes and improving spatial skills	Middle East Technical University, Graduate School of Natural and Applied Sciences, Ankara	Mixed	Pre-school period	2017
The effect of inquiry-based activities applied in natural open spaces on children's geometric and spatial thinking skills	Hacettepe University Department of Early Childhood Education, Ankara	Quantitative	Pre-school period and teachers	2017
The effect of preschool geometry education program on children's geometry skills and creative thinking	Gazi University Institute of Educational Sciences Department of Elementary Education, Ankara	Quantitative	Pre-school period	2018

Table 2 shows 5 doctoral dissertations on early geometry skills found in this study. No doctoral dissertations were found in the search made with the keywords "geometry in preschool period" and "geometry in early childhood" in the database. 1 doctoral dissertation was found in the search with the keyword "early geometry skills" while 3 doctoral dissertations in the search with the keyword "geometric shape", and 1 doctoral dissertation in the search with the keyword "geometric and spatial thinking" were available. When the doctoral dissertation studies were examined, no study directly related to the geometry in pre-school period was found between 2000-2010. It was seen that research have been carried out since 2011. Studies conducted are about geometry skills and geometric shapes (Kesicioğlu, 2011; Sezer, 2015; Gecü Parmaksız, 2017; Korkmaz, 2017; Kılıç, 2018).

It was found out that the doctoral dissertations included in the research were prepared under 4 different universities. It was seen that 20% of the dissertations originated from Gazi University. It can be said that Gazi University contributed to this field with a higher number of doctoral dissertations. When the methods of doctoral dissertations were examined, it was determined that four studies were carried out with quantitative method and one study was carried out with mixed design. It is seen that the study group of all doctoral dissertations on geometry consisted of preschool children while in one of the dissertations preschool children and teachers formed the study group.

5. What is the distribution of theses on geometry in preschool period by subject?

Table 3. Distribution of theses on geometry in preschool period by subject

Subjects (Master's Theses)	**%**	**f**
Effectiveness of traditional and constructivist methods in the acquisition of mathematical concepts	10	2
Examining the criteria used to recognize basic geometric shapes.	5	1
Effectiveness of computer aided education and traditional education methods in gaining the concept of number and shape	10	2
Effectiveness of Piaget and Montessori educational methods in developing concepts related to numbers and geometric shapes	5	1
The effect of drama method on developing the perception of shape and number concept	5	1
Recognizing the basic geometric shapes and determining how they perceive the concepts used and geometric shapes while distinguishing the shapes from each other	5	1
The effect of narrative method on mathematics achievement	5	1
The effect of Frobel gifts on the geometry skill	5	1
The relationship between visual perception skills and geometry skills	5	1
Relationship between learning centers preference, geometry skills	5	1
The relationship between executive function and geometry skills	5	1
The relationship between attention, geometry, and phonological awareness	5	1
The effect of concept education on the development of the concepts of geometric shapes and numbers	5	1
Sub-total	75	15
Subjects (Dissertations)	**%**	**f**
The effect of direct instruction method and computer-aided education program on geometric shape acquisition	5	1
Developing the Early Geometry Skill Test and examining the skill	5	1
The effect of augmented reality activities on understanding geometric shapes and improving spatial skills	5	1
The effect of inquiry-based activities on geometric and spatial thinking	5	1
The effect of the geometry education program on geometry skills and creative thinking	5	1
Sub-total	25	5
Total	**100**	**20**

According to table 3 which presents the findings related to the master's theses, the trend of research topics were as follows: effectiveness of traditional and constructivist methods in the acquisition of mathematical concepts and basic geometric shapes (10%), the effectiveness of computer-aided education and traditional education methods (10%), the effectiveness of Piaget and Montessori methods (5%), The effectiveness of the drama method (5%), the narrative method (5%), the effectiveness of Frobel gifts (5%) and the effectiveness of concept education (5%). Meanwhile, the criteria used in recognizing and distinguishing basic geometric shapes (5%), and determining the concepts and how geometric shapes are perceived when recognizing basic geometric shapes and distinguishing shapes from each other (5%) were also studied in the theses. In the relational aspect, the relationships among geometry skills and visual perception skills (5%), children's learning center preferences (5%), executive function skills (5%), attention skills and phonological awareness (5%) were studied.

When the doctoral dissertations were examined, mostly studied topics were as follows: the development of the Early Geometry Skill Test and the examination of the skill (5%), the effectiveness of direct instruction method and computer-aided education in the acquisition of the geometric shape concept (5%), the effectiveness of augmented reality activities (5%), the effectiveness of inquiry-based activities (%) 5) and the effectiveness of the geometry education program (5%).

6. What is the distribution of studies on geometry in preschool period by sampling method?

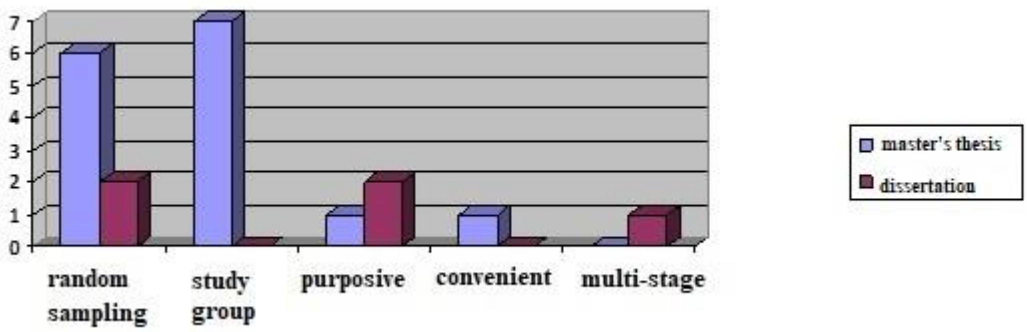

Figure 3. Distribution of studies on geometry in preschool period by sampling method

In line with the findings shown in Figure 3, it was found out that 46.66% (n = 7) of the master’s theses included in this study used a study group, 40% (n = 6) used random sampling, 6.66% (n = 1) used purposive sampling and 6.66% (n = 1) used the convenient sampling method. In doctoral dissertations, it was determined that 40% (n = 2) used random sampling, 40% (n = 2) purposive sampling, and 20% (n = 1) multi-stage sampling method. Accordingly, it was seen that random sampling method was preferred most in theses and dissertations. In the second order, it was seen that the determining a study group was preferred in the studies examined.

Conclusion and Suggestions

In this research, theses and dissertations on early geometry skills were reviewed. Based on the results of the analysis made within the scope of the research, it can be said that scientific studies on geometry skills have gained more importance over the years. The fact that early geometry skills are dealt with from different dimensions enriches the literature, but it is not considered sufficient. More scientific research is needed on early geometry skills. Suggestions with regard to the results obtained from this study which aims to review the thesis and dissertations on early geometry skills and published in Turkey in the years 2000-2020 are given below:

According to the results of this research, academics can direct their graduate students to study on early geometry skills. In this context, comprehensive master's theses and doctoral dissertations, which will serve as the basis for early geometry skills programs while providing information on the investigation of children's geometry skills, and leading to the development of early geometry skills, are required. In this study, only master's theses and doctoral dissertations published in Turkey were discussed. Researchers can conduct new studies by scanning the different databases such as Web of science, ULAKBİM, and Google Scholar which list national and international research carried out so far. Longitudinal studies on the development of early geometry skills and qualitative and mixed studies can be conducted more. More research can be done to link early geometry skills with different areas of interest.

Notes

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Enhanced 7E Instructional Model towards Enriching Science Inquiry Skills

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Abstract: This study enhanced the 7E instructional model towards enriching the science inquiry skills of senior high school learners in General Chemistry 1. A total of 136 Grade 12 learners enrolled in the Science, Technology, Engineering, and Mathematics (STEM) strand participated in the study. The study was composed of three phases. In Phase I, the generated themes nature of topics, learning environment, learner-related and teacher-related issues were found to be the causes of difficulty in science inquiry skill enrichment. The learners' meaningful learning experiences during the process were encapsulated in Phase II. Finally, Phase III used the generated themes in the enhancement of 7E instructional model promoting inquiry-based and constructive learning among senior high school learners.

Keywords: 7E instructional model, Interactive courseware, Science inquiry skills enrichment, General Chemistry 1, Senior high school

Introduction

To adapt to this ever-changing and fast-paced society improvement and sustainability of Philippine quality education is an utmost priority (Durban & Catalan, 2012). With the establishment of K to 12 curriculum, the Department of Education hoped to solve the country's needs (Abulencia, 2015) and to keep up with the global educational reform (Belecina & Ocampo, Jr., 2018). Likewise, learners are taught to think scientifically, design scientific inquiry, interpret data and evidences, and draw conclusions (van Uum et al., 2017). This encompasses science education's goal in the country's current curriculum. However, with the unprecedented events brought about by the COVID-19 pandemic schools forcefully closed its operation on March 2020 to contain its spread which may affect the welfare of learners, teachers, and educational stakeholders inadvertently. This compromised the Department of Education's plans to open the classes every June of the year. As a result, the department released D.O. No. 12, s. 2020 establishing the adoption of Basic Education Learning Continuity Plan (BE-LCP) that contains sets of educational interventions through necessary K-12 curriculum adjustments, alignment of learning materials, deployment of multiple learning delivery modalities, provision of trainings for

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teachers and school leaders, and proper orientation of parents/guardians. In general, majority of the learners preferred modular distance learning (MDL) as they find it difficult to cope up with the challenges posed by online distance learning such as lack of internet and gadgets to use. However, empirical observations and interviews with the parents/guardians depicted that most of the learners find it difficult to learn the concepts in the module due to lack of teacher guidance and facilitation for learning.

Science, Technology, Engineering and Mathematics (STEM) strand of senior high school program under the K to 12 Basic Education Curriculum is designed to produce secondary level graduates capable to take science, research, mathematics, and engineering-related courses in tertiary level. They are expected to be the next frontier of scientifically-inclined professionals for the country (Caballero & Cabahug, 2015). Thus, the curriculum is purposively designed for mathematics and science-inclined learners as answers to the long-decade problem of low number of mathematics and science practitioners (Rabacal & Alegato, 2017). It was pointed that the low science professionals may be attributed to the poor academic performance of students in mathematics and the low inquiry skill levels of learners in Science that hinders them to excel in science-related endeavors (Chu et al., 2016). The decline in the interest in Science along with insufficient instructional materials affect the progress of the discipline (Hulleman & Harackiewicz, 2009). One of the subjects in senior high school which experienced these dilemmas is General Chemistry 1 which is a specialized subject of the said strand in the senior high school program.

In the education perspective, the evolution of 7E instructional model is the product of collaborative ideas brought about by constructivist and inquiry-based learning approaches in science teaching (Lubiano & Magpantay, 2021; Suardana et al., 2018). Williams (2017) emphasized Dewey's ideas about inquiry as the starting point to enrich skills such as creativity, communication, ICT, literacy, and numeracy needed in the modern era. Consequently, science curriculum implements inquiry-based learning in order to create science-oriented learners with the necessary science process skills (Chiang et al., 2014). However, Ješková et al. (2018) found that the senior high school learners' inquiry level remain low. This is because they are not involved in inquiry activities despite finishing elementary and junior high levels.

To solve the existing problem, science teachers need to adjust their teaching practices on how their students learn in the 21st century. In order to implement greater student-centered and inquiry-based strategies towards learning, Hennessy et al. (2007) and Scott et al. (2011) stressed the implementation of the constructive, collaborative, integrative, inquiry-based, and reflective (*2C2I1R*) teaching approaches which are essential in developing instructional materials to improve the learning outcome and to address the learners' needs. Quality education means empowered learning and serves as basis for the implementation of the instructional model where learners work independently or collaboratively in developing concepts facilitated by teachers (Stohlmann et al., 2012).

In this modern era of technology, teaching materials are developed to cope with the ever changing needs of the learners (Klimova, 2019). The application of technological gadgets in the classroom encompassed the conventional way of delivering lessons in Science. Concepts to be learned should be reflective in the learner's everyday learning experiences to retain the concepts in their mind (Samaresh, 2017). The lack of interest and motivation in science classes leads to low academic achievement (Hubber & Loong, 2013). This, by far, serves as an inspiration to address the greater need to bridge the gap between technology and inquiry as an offshoot to the enrichment of learners' science inquiry skills using innovative instructional material. With the above-mentioned circumstances, the study was conducted to solve the existing problems and attain the benefits of an enhanced 7E instructional model with integration of the technology-based instructional material in General Chemistry 1.

Theoretical Framework

The use of web-based inquiry learning coupled with 7E instructional model is anchored on constructivist learning theory which has emerged as a prominent approach to teaching for decades. The works of Dewey (1986), Montessori (1965), Piaget (1964), Bruner (1985), and Vygotsky (1978) provided historical precedents for constructivist learning theory. Constructivist learning approach as mentioned by Balta (2016) spurred idea that learners construct knowledge in an active process where they combine previous learning to the newly acquired one. In addition, Yoders (2014) instigated that the use of constructivist learning cycle models in science teaching affects a particular science course. This happens as it equips content of the courses, proliferates learners' attention towards courses, guarantees permanent learning, revolutionizes students' prejudgments towards science, and inspires learners in an entertaining and fruitful manner.

Constructivist approach as Samaresh (2017) mentioned helps in achieving a meaningful learning in science concepts among the secondary learners. Further, Schcolnik and Abarbanel (2006) described constructivists view learning as a formation of abstract concepts in mind to represent reality. Learning occurs when a learner constructs internal representations for his/her unique version of knowledge. Adesoji and Idika (2015) emphasized the use of interactive activities in which learners play active roles can engage and motivate learning more effectively than activities where learners are passive. This is natural to expect that self-directed, interactive learning will improve learning outcome with typical less interactive classroom environments relying on instructors, textbooks, and lectures (Dewey, 1986). Individuals are assumed to learn better when they discover things by themselves and when they control pace of learning.

Finally, Eisenkraft (2003) expanded the E instructional model where a problem or a question was provided. They would be required to plan how to solve an experimental problem or to test a hypothesis. Therefore, the students have to formulate an investigation procedure to find undetermined outcome by them. It allows the students to think like scientists. Later they acquire knowledge and develop their own understanding of concepts, principles, or even theories. Thus, the researcher combined the concepts of science inquiry skills, interactive courseware, and the 7E instructional model in the study to fill the gap.

Research Objectives

This study aimed to enhance the 7E instructional model model integrated with the interactive courseware in General Chemistry 1 among Grade 12 learners of Science, Technology, Engineering and Mathematics (STEM) strand, S.Y. 2020-2021.

Specifically, it sought answers to the following objectives:

1. Determine and explain the causes of difficulties in enriching the science inquiry skills in General Chemistry 1 as perceived by teachers and learners;
2. Encapsulate the meaningful learning experiences of learners in enriching science inquiry skills using the developed technology-based teaching material integrated in the 7E instructional model in General Chemistry 1; and
3. Enhance the 7E instructional model integrated with interactive courseware towards science inquiry skills enrichment.

Method

Research Context

This study was conducted in two (2) selected public secondary schools offering the Science, Technology, Engineering, and Mathematics (STEM) strand of the K to 12 Senior High School program in the Schools Division of Quezon, Philippines. These were Dr. Maria D. Pastrana National High School in Mauban, 4330 and Lutucan Integrated High School in Sariaya 4301. To maintain confidentiality of the data gathered, the school-respondents were coded as public schools A and B. Further, the schools were chosen because they were offering Science, Technology, Engineering, and Mathematics (STEM) strand with two (2) comparable sections. Likewise, the schools pioneered the implementation of STEM strand for several years which qualified them for the study.

Participants

Two (2) groups of Grade 12 students in these schools served as the control and experimental groups. A total of 136 respondents participated in the study with 68 learners each in the control and experimental groups carefully assigned using matching variables. On the other hand, 50 science teachers were chosen purposively from the junior and senior high schools to determine the level of acceptability of the technology-based instructional material in General Chemistry 1.

Measures

Prior to the actual conduct of the study, the researcher assessed the pre-level inquiry skills of the respondents using the developed and validated test instrument. Afterwards, the researcher analyzed the respondents' answers on the inquiry skills questions. Furthermore, the researcher assigned the respondents into the control and experimental groups using the matching variables *pre-level inquiry skills scores*, and *Grade 11 general average*. On the other hand, the General Chemistry 1 interactive courseware, to be used as the study's intervention, was crafted as an all-Filipino, locally developed, all-original, and offline-based educational platform available both as web-based and Android-compatible mobile application. With the assistance of an expert software developer, the researcher carried out the development of the interactive courseware's content composed of 5 main parts namely *overview, pre-lab discussion, inquiry skill activity, post-lab discussion*, and *evaluation*. These parts were integrated with the 7E instructional model lesson exemplars for each topic. To ensure the correctness of the content of the application, a content validation among Science teachers and ICT experts was facilitated. Any errors identified during content validation were integrated to improve the application.

For three months, learners in the control group were taught using the conventional teaching while those in the experimental group were supplemented with the General Chemistry 1 interactive courseware integrated in 7E instructional model lesson exemplar. At the end of the experimental stage, the researcher facilitated the post-level inquiry skills test among learners in the control and experimental groups. Lastly, the significant difference between the posttest scores of the two groups was calculated, tabulated, analyzed, and interpreted statistically. A day was allotted for the conduct of focus group discussion and semi-structured interview among selected respondents in the experimental group with regards to their meaningful learning experiences in the utilization of interactive courseware in General Chemistry 1 towards enriching their science inquiry skills. Transcripts were analyzed thematically. This was conducted manually from the initial to final coding stages. These qualitative and quantitative results served as bases in the development of an enhanced 7E instructional model in enriching the science inquiry skills in General Chemistry 1.

Statistical Analyses

Weighted mean was applied to determine the level of teachers' and learners' responses regarding the causes of difficulties in enriching the science inquiry skills. To determine the significant differences of the pre-level inquiry skills, and Grade 10 Science grades before the conduct as matching variables, and the post-level inquiry skills after the conduct between the control and experimental groups, the t-test for independent sample means was used.

Ethics

An informed consent and protection from harm was given to the participants beforehand. This was done to ensure that the respondents participated in their own will, they would not be harmed, and any data to be gathered in the study were treated with strict confidentiality. Their anonymity was greatly taken with great consideration so as to keep information in private. In the qualitative phase, it was emphasized that to keep ethical consideration the researcher developed an ethical perspective that was close to one's personal and ethical position, to seek research participants' informed consent, to determine the broader social principles that affect one's ethical stance, and to remain truthful to the answers gathered and maintain composure to the participants to avoid disclosure of the findings. On the other hand, prior to the conduct of the study letters to the Principal, and parents were disseminated first to inform them about the conduct of the study. The researcher let the manuscript underwent plagiarism checking to ensure citation and acknowledgement of secondary sources. Finally, the results of the study were willingly shared to all concerned so as to effect positive change and to help beneficiaries disseminate the results for further improvement.

Results

In the study, the researcher sought to address the current problem. These are first-hand experiences of the teachers and learners both in the inquiry process. Hence, a thorough quantitative and qualitative data collection and analyses were instigated. This was done to establish a strong baseline data in order to provide possible solution to the problems identified. In the first phase, the researcher determined and explained the causes of difficulties in the learners' enrichment of their science inquiry skills.

Phase I. Causes of difficulties in the enrichment of Science Inquiry Skills in General Chemistry 1

Part A. Teachers' and Learners' Responses on the Causes of Difficulties in Science Inquiry Skills Enrichment

Table 1 displays the science teachers' and the students' responses regarding the causes of difficulties in enriching the science inquiry skills in General Chemistry 1 in terms of nature of topics. It reveals that the science teachers and the learners **strongly agree** that the *nature of topics* makes the enrichment of science inquiry skills difficult, which is evident in the average weighted means of **3.46** and **3.42**, respectively.

Table 1. Teachers' and Learners' Responses Regarding the Nature of Topics as a Cause of Difficulties in Enriching the Science Inquiry Skills

Statements	Teachers' Responses				WM	DR	Learners' Responses				WM	DR
	4 (SA)	3 (A)	2 (D)	1 (SD)			4 (SA)	3 (A)	2 (D)	1 (SD)		
1. Inquiry skills activities are embedded in each Science class.	14	12	0	0	3.54	SA	68	0	0	0	4.00	SA
2. Topics in Chemistry require intellectual thought and discernment.	24	2	0	0	3.92	SA	65	1	2	0	3.93	SA
3. Chemistry has a logical order of topics which makes it easy to grasp the concepts.	26	0	0	0	4.00	SA	66	1	1	0	3.96	SA
4. Topics taught in the class are asked using high level of questioning during assessment in Chemistry.	20	3	3	0	3.65	SA	64	2	2	0	3.91	SA
5. In order to promote inquiry-based learning, Chemistry does not emphasize the use of evidences from the activities in constructing explanations. *	0	0	0	26	4.00	SD	0	1	3	64	3.93	SD
6. Topics are not presented with increasing levels of complexity from one lesson to another using spiral progression towards deeper understanding of key concepts.*	0	0	3	23	3.88	SD	13	0	17	38	3.18	D
7. Some topics in Chemistry require the application of Mathematics which makes the subject more difficult to understand and appreciate. *	8	4	3	11	2.65	D	25	22	12	9	2.07	A
8. Chemistry has topics that seem unclear and complex in nature such as matter; precision and accuracy; atoms, molecules, and ions; stoichiometry; and gas laws.	5	6	5	0	2.00	A	20	5	18	12	2.40	A
Average Weighted Mean					**3.46**	**SA**					**3.42**	**SA**

Legend: **3.25 – 4.00** Strongly Acceptable (SA)/ Strongly Agree (SA); **2.50 – 3.24** Acceptable (A)/ Agree (A); **1.75 – 2.49** Fairly Acceptable (FA)/Disagree (D); **1.00 – 1.74** Not Acceptable (NA)/ Strongly Disagree (SD)

In connection to the nature of topics, the use of higher order thinking skills (HOTS) questions can improve the quality of science teaching in the future (Darling & Hammond, 2017). This is similar to the study of Seman et al. (2017) that poor critical and creative thinking skills of the learners nowadays hinder their understanding of the concepts and nature of the subject matter. On the other hand, Kizilaslan et al. (2012) signified that inquiry learning is essential strategy to those scientifically-inclined individuals. In General Chemistry, learners can succeed if they can think mathematically where calculating numbers in solving problems are necessary

(Sugiharti et al., 2019). This is supported by the study of Antwi (2013) where most of the time learner's mathematical solutions in Chemistry were not checked and even corrected by teachers ahead of time to avoid misconception. Moreover, it was argued that the primary reason why Chemistry remained difficult was its mathematical nature (Kennedy et al., 2014). Thus, the *nature of topics* as one of the factors/issues hindering the enrichment of learners' science inquiry skills. Learners developed boredom in Chemistry when faced with unclear concepts to them. Furthermore, they become dissociated with the ideas they found inapplicable to their daily living.

Table 2. Teachers' and Learners' Responses Regarding the Learning Environment as Cause of Difficulties in Enriching the Science Inquiry Skills

Statements	**Teachers' Responses**				**WM**	**DR**	**Learners' Responses**				**WM**	**DR**
	4 (SA)	**3 (A)**	**2 (D)**	**1 (SD)**			**4 (SA)**	**3 (A)**	**2 (D)**	**1 (SD)**		
9. Chemistry classes are held in conducive learning atmosphere.	26	0	0	0	4.00	SA	35	32	1	0	3.50	SA
10. The inquiry skill activities provided consist of practical applications.	21	5	0	0	3.81	SA	25	26	17	0	3.12	A
11. ICT-based learning materials are provided to promote 21st century learning.	10	2	14	0	2.85	A	33	22	13	0	3.29	SA
12. School has facilities like science laboratory, learning centers, audio-visual rooms, among others to promote inquiry learning.	26	0	0	0	4.00	SA	61	7	0	0	3.90	SA
13. Poor background in Chemistry during junior high school finds it difficult to promote inquiry learning. *	17	4	3	2	1.62	SA	38	16	2	12	1.82	A
14. Available learning materials are inadequate to support the class. *	11	4	5	6	2.23	A	38	14	7	9	1.81	A
15. Lack of visual presentation makes it difficult to comprehend the lessons. *	15	4	4	3	1.81	A	13	13	35	7	2.53	D
16. Unplanned inquiry skill activities affect the teaching-learning process. *	18	4	3	1	1.50	SA	38	17	3	10	1.78	A
Average Weighted Mean					**2.73**	**A**					**2.72**	**A**

Legend: **3.25 – 4.00** Strongly Acceptable (SA)/ Strongly Agree (SA); **2.50 – 3.24** Acceptable (A)/ Agree (A); **1.75 – 2.49** Fairly Acceptable (FA)/Disagree (D); **1.00 – 1.74** Not Acceptable (NA)/ Strongly Disagree (SD)

Table 2 displays the science teachers' and students' responses regarding the causes of difficulties in enriching the science inquiry skills in General Chemistry 1 in terms of learning environment. It displays that the science teachers and the learners generally both **agree** that the *learning environment* makes the enrichment of science inquiry skills difficult to enrich, which is evident in the average weighted means of **2.73** and **2.72**, respectively. Learning happens when lessons are taught in a learning environment that promotes inquiry. Hence, this contributes not only to get the interests of the learners, but also respond to individual difference. Jocz et al. (2014) found that existing problems on facilities and instructional materials affect in learning the topics in General Chemistry 1. This has negative effect on the achievement of the learning competencies which are necessary in developing their inquiry skills. This is in line with the findings of Orbe et al. (2018) that sufficient facilities are needed in understanding Chemistry in the Philippine K to 12 setting.

Truly, having conducive learning atmosphere affects the perspective of learners towards a subject. Observation showed that studying in a place where there is insufficient lighting system, uncomfortable and noisy classroom, and lack of science laboratory equipment and facilities deplete learners' enthusiasm to develop greater understanding in the subject. This is in connection to the findings of Jocz et al. (2014) that the poor background in Chemistry makes the development of inquiry more difficult. Sadly, learners do not have prior knowledge about Chemistry concepts. As a result, there is difficulty in the spiraling of the lessons. Consequently, the researcher felt that deepening of the concepts is sacrificed which adversely affect the next lessons.

Table 3 describes science teachers' and students' responses regarding causes of difficulties in enriching science inquiry skills in General Chemistry 1 in terms of learner-related issues. It reveals that the science teachers and the learners generally both **agree** that the *learner-related issues* make enrichment of science inquiry skills difficult to enrich, which is evident in the average weighted means of **2.79** and **2.94**, respectively.

Table 3. Teachers' and Learners' Responses Regarding the Learner-related Issues as Cause of Difficulties in Enriching the Science Inquiry Skills

Statements	Teachers' Responses						Learners' Responses					
	4 (SA)	**3 (A)**	**2 (D)**	**1 (SD)**	**WM**	**DR**	**4 (SA)**	**3 (A)**	**2 (D)**	**1 (SD)**	**WM**	**DR**
17. Learners are participative in the inquiry-based skill activities.	1	0	5	20	1.31	SD	33	25	7	3	3.29	SA
18. Learners prefer independent and/or collaborative learning.	23	2	1	0	3.85	SA	47	11	7	3	3.50	SA
19. Learners can easily apply concepts in their daily life.	23	3	0	0	3.88	SA	56	10	2	0	3.79	SA
20. Learners perceive varying concepts in Chemistry easy to	19	5	2	0	3.65	SA	43	12	5	8	3.32	SA

enrich the science inquiry skills.												
21. Learners cannot enrich their science inquiry skills on their own. *	0	0	12	14	3.54	SD	7	3	13	45	3.41	SD
22. Learners cannot easily understand the scientific "language" used in studying Chemistry. *	25	1	0	0	1.04	SA	10	25	25	8	2.46	A
23. Learners do not have access to innovative ICT-based instructional materials promoting 7E instructional model. *	0	1	2	23	3.85	SD	40	12	6	10	1.79	A
24. Learners have insufficient schema in mathematical application necessary to solve problems in Chemistry. *	23	1	2	0	1.19	SA	36	13	7	12	1.93	A
Average Weighted Mean					**2.79**	**A**					**2.94**	**A**

Legend: **3.25 – 4.00** Strongly Acceptable (SA)/ Strongly Agree (SA); **2.50 – 3.24** Acceptable (A)/ Agree (A); **1.75 – 2.49** Fairly Acceptable (FA)/Disagree (D); **1.00 – 1.74** Not Acceptable (NA)/ Strongly Disagree (SD)

Rotgans and Schmidt (2011) found that independence and engagement of learners in an inquiry-based learning promote cognitive structure. In turn, Science is developed not just to produce learning but rather to engage learners in the learning process. This can only be realized if the learners are enjoying their works independently or collaboratively. Mahajan and Singh (2015) found that poor study habit added with the spoon-feeding done by the teachers make them more passive. In addition, learners do not actively participate in the accomplishment of inquiry skills activities due to absence of interest, motivation, and enthusiasm. This affects the absorption and application of Chemistry concepts in real life situation (Cetin-Dindar & Geban, 2011). They reiterated that Chemistry remains confusing among the learners due to scientific language barrier. This might be expected when scientific context is taught in its technical aspects. In reality, learners are no longer fond of developing their vocabulary in the second language, and more so, in Science-related subjects.

Likewise, Ralph and Lewis (2018) stated that poor mathematical skills increase the difficulty of Chemistry Incidentally, the researcher has observed that some learners tend to use their mobile phones during classroom discussion. It prompted him to develop a supplementary material that can assist the learners to easily access information at their own disposal. Sarac and Tarhan (2017) recommended the integration of 7E instructional model in the development of ICT-based material to address complex ideas in Chemistry. This, in turn, leads to opening an avenue of learning where learners learn the concepts seamlessly.

Table 4. Teachers' and Learners' Responses Regarding the Teacher-related Issues as Cause of Difficulties in Enriching the Science Inquiry Skills

Statements	Teachers' Responses				WM	DR	Learners' Responses				WM	DR
	4 (SA)	3 (A)	2 (D)	1 (SD)			4 (SA)	3 (A)	2 (D)	1 (SD)		
25. Teachers have adequate pedagogical content knowledge in Chemistry.	22	4	0	0	3.85	SA	48	15	2	3	3.59	SA
26. Teachers apply constructivist approach in delivering the lessons.	18	4	4	0	3.54	SA	12	15	10	31	2.12	D
27. Teachers provide complete explanations about the concept during abstraction.	22	4	0	0	3.85	SA	37	31	0	0	3.54	SA
28. Teachers act as facilitator by letting the learners work independently and/or collaboratively.	12	13	1	0	3.42	SA	12	46	5	5	2.96	A
29. Teachers do not promote the use of 7E instructional model in facilitating an inquiry-based learning in the classroom. *	0	5	9	12	3.27	SD	6	13	26	23	2.97	D
30. Teaching Chemistry still practices conventional teaching approach (lecture, recitation, slide deck presentation, among others).	17	9	0	0	1.35	SA	25	10	13	20	2.41	A
31. Spiral progression approach is not practiced in the delivery of Chemistry lessons without any connection of the lessons formerly learned to the present ones. *	0	1	9	16	3.58	SD	11	3	14	40	3.22	D
32. Use of innovative teaching materials in Chemistry is not practiced in order to uplift learner's interests and motivation in the subject. *	21	4	1	0	1.23	SA	47	2	6	13	1.78	A
Average Weighted Mean					**3.01**	**A**					**2.82**	**A**

Legend: **3.25 – 4.00** Strongly Acceptable (SA)/ Strongly Agree (SA); **2.50 – 3.24** Acceptable (A)/ Agree (A); **1.75 – 2.49** Fairly Acceptable (FA)/Disagree (D); **1.00 – 1.74** Not Acceptable (NA)/ Strongly Disagree (SD)

Table 4 shows the science teachers' and students' responses regarding the causes of difficulties in enriching the science inquiry skills in General Chemistry 1 in terms of teacher-related issues. It reveals that the science teachers and the learners both **agree** that *teacher-related issues* make the enrichment of science inquiry skills difficult to enrich, as shown in the average weighted means of **3.01** and **2.82**, respectively.

Agogo and Onda (2014) found that teachers' qualification and students' perceived difficult concepts in Chemistry have no relation at all. However, they recommended that teachers must be professionally qualified to teach the subject to help the students learn Chemistry more effectively. In addition, Sadler et al. (2013) stated that half of the teaching workforce in secondary and tertiary levels are not specialized in the discipline. Further, Orbe et al. (2018) concluded that the Chemistry instruction is realistic, changing, and creative which requires competent and highly qualified teachers. It can be quoted that "spiraling of Chemistry concepts is learner-centered, advanced, and sophisticated yet it is not concentrated and extensive" (Orbe et al., 2018). Thus, teachers play crucial role in the implementation of a successful inquiry-based learning. It requires students to realize the full potential to develop inquiry skills and appreciate the importance of learning every concept for lifelong learning. Shift from traditional to inquiry-based teaching necessitates teachers to innovate ways on how to enrich learner's meaningful experiences (García-Carmona et al., 2017). Inevitably, this is supported by Čipková & Karolčík (2019) who reiterated that teachers have to give considerable attention on how to develop the learners' science inquiry skills in their science lessons to guide them in applying concepts learned in real life situations. Henceforth, this calls for an abrupt decision to address the problem with regards to the enrichment of the learners' science inquiry skills which are prerequisite to the tertiary courses in science, technology, engineering, and mathematics disciplines. Moreover, challenges lie ahead which entails the collaborative efforts of teachers, and learners in order to overcome them.

Part B: Challenges of Science Inquiry Skills Enrichment

Being one of the natural sciences, Chemistry is generally recognized as one of the most difficult subjects in basic secondary education level (Cardellini, 2012). Yet, Wolfson et al. (2014) described this discipline as a scientific breakthrough amidst the challenges that strived due to basic human qualities like creativity, reasoning, and inquiry skills. The generated themes from the coding analysis (Figure 1) summarized that science inquiry skills enrichment in General Chemistry 1 is hindered by these issues/ factors namely *Nature of Topics, Learning Environment, Learner-related Issues* and *Teacher-related issues.* With these factors identified to be affecting the science inquiry skills, education stakeholders such as teachers, learners, parents, school administrators, curriculum developers, and the national government are facing challenges to take effect the goal of providing enabling environment developing 21st century society (Jocz et al., 2014).

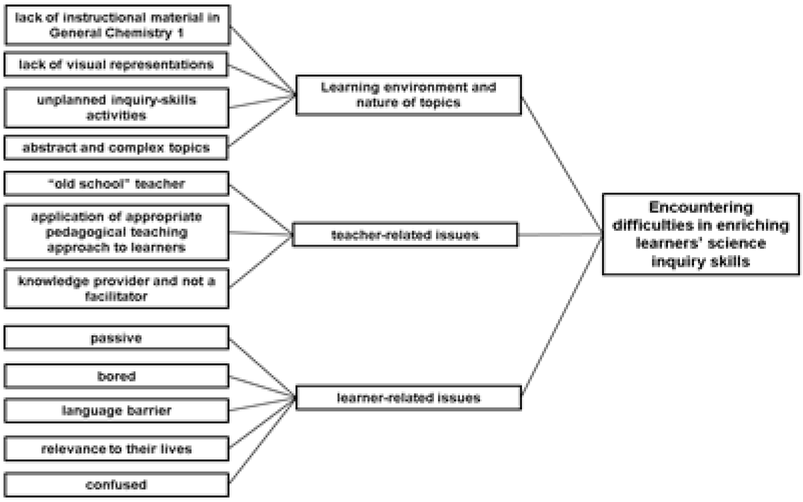

Figure 1. Encountered difficulties in enriching learners' science inquiry skills

Empirically, asking questions is innate to a child. This can be readily observed when one is curious about the things around. In turn, a child learns to investigate until coming up with a solution. Likewise, teachers should develop ways or materials that will enable the learners to enrich their inquiry skills through self-assessment (Zimmerman & Klahr, 2018). Learners have the ability to construct their own learning. In addition, they have the tendency to appreciate things when they learn it though first-hand experience. Morally, Orbe et al. (2018) emphasized that the inquiry-based learning is employed in Chemistry instruction in the K to 12 curriculum. Scientific values should be sought to develop along the process. Thus, it engages learners to become motivated, collaborative, independent, and innovative individuals capable of answering their own queries through investigation. The researcher thought of bringing change in addressing identified causes of difficulties in enriching science inquiry skills in General Chemistry 1.

Phase II. Encapsulation of learners' meaningful learning experiences in enriching their science inquiry skills

With the advent of Industrial Revolution 4.0, the global education sector is focusing more on digital literacy to promote learning in schools (Dewi et al., 2019). As part of globalization and modernization, the challenge among teachers and other education stakeholders lies on the use of available technology to capacitate the learners in creating their own meaningful learning experiences that will enrich their 21st century inquiry skills (Gupta et al., 2015). Chemistry, one of the natural science disciplines, requires learners to apply concepts learned in the classroom to their real-life situations. Thus, technology can be tapped to develop Chemistry learning materials readily available in their mobile phones where learners of today are too passionate about (Shin, 2015). Innovation in the field of Chemistry education must be realized to increase learners' motivation which will result to greater learning outcomes. With this in mind, the researcher developed a way to innovate an instructional material in Chemistry to address the factors that causes difficulties in enriching the science inquiry skills.

Part A. Comparison of variables between the Control and Experimental Groups

Table 5. Significant Difference between the Profile of the Control and Experimental Groups in terms of Pre-level Inquiry Skills Score

School	Group	N	Highest Score	Lowest Score	Mean	SD	Mean Difference	t-value	*p-value	Interpretation
A	Control	42	18	3	10.67	3.65	0.53	1.99	0.77	Not Significant
	Experimental	43	18	1	10.14	4.22				
B	Control	26	17	5	11.60	2.98	0.18	2.01	0.75	Not Significant
	Experimental	25	22	7	11.23	3.29				
Overall	**Control**	**68**	**18**	**3**	**10.88**	**3.53**				
	Experimental	**68**	**22**	**1**	**10.68**	**3.88**	**0.20**	**1.98**	**0.75**	**Not Significant**

**Level of Significance at 0.05*

Table 5 indicates the significant differences between the profiles of respondents in the experimental and the control groups in terms of their pre-level inquiry skills scores. Since the p-values **(0.77 and 0.75)** of the two groups in Schools A and B are higher than 0.05 level of significance, the researcher fails to reject the null hypothesis. Likewise, general result reveals that the p-value **(0.75)** is also higher than 0.05 level of significance. Thus, it means that there is no significant difference between the profiles of respondents in the experimental and the control groups in terms of pre-level inquiry skills scores as one of the matching variables. Overall, the control and the experimental groups have the same performance level based on first matching variable before the conduct of the study. Gay, Mills, and Airasian (2012) described the importance of a careful random selection and assignment of respondents at the onset of experimental process. Moreover, Hanita et al., (2017) emphasized confounders such as the pre-assessment scores in an experiment that serve as baseline characteristics must be of similar so that there will be no bias and all observed changes in the teaching-learning process can be attributed to the intervention used. Hence, the researcher has selected groups that are of the same level before the onset of the study in determining the effectiveness of the instructional material. Another matching variable strengthened formation of two groups discussed quantitatively in the next table.

Table 6. Significant Difference between the Profile of the Control and Experimental Groups in terms of Grade 11 General Average

School	Group	N	Highest Score	Lowest Score	Mean	SD	Mean Difference	t-value	*p-value	Interpretation
A	Control	42	97	81	90.40	3.05	0.04	1.99	0.93	Not Significant
	Experimental	43	94	81	90.44	3.04				
B	Control	26	96	91	93.96	1.54	0.42	2.01	0.61	Not Significant
	Experimental	25	97	90	93.54	1.76				
Overall	**Control**	**68**	**97**	**81**	**91.60**	**3.11**	**0.14**	**1.98**	**0.81**	**Not Significant**
	Experimental	**68**	**97**	**81**	**91.74**	**3.10**				

**Level of Significance at 0.05*

Table 6 indicates the significant differences between the profiles of respondents in the experimental and the control groups in terms of their Grade 11 general average. Since the p-values **(0.93 and 0.61)** of the two groups in Schools A and B are higher than 0.05 level of significance, the researcher fails to reject the null hypothesis. Likewise, general result reveals that the p-value **(0.75)** is also higher than 0.05 level of significance. Thus, it means that there is no significant difference between the profiles of respondents in the experimental and the control groups in terms of their Grade 11 general average as one of the matching variables. Overall, the control and the experimental groups have the same level of performance based on second matching variable before the conduct of the study.

Gay et al. (2012) described the importance of the careful random selection and assignment of respondents at the onset of the experimental process. However, White and Sabarwal (2014) reminded that the lack of good quality data is a barrier in the matching process. Thus, aside from the results of pre-assessment, Hanita et al. (2017) emphasized another confounder which is the learners' previous academic achievement performance as baseline characteristic before the start of a study to ensure the similarity of the two groups being compared. This posed rejection of bias observed pointing that intervention used has made the necessary improvement. Hence, the researcher has selected groups that are of the same level before the onset of the study in determining the effectiveness of the instructional material. The researcher, in order to ascertain significant difference between experimental and control groups followed carefully planned procedures and appropriate statistical measures discussed in the next section.

A week before the onset of the study, the researcher assessed the pre-level inquiry skills of the respondents using the developed and validated test instrument. Afterwards, the researcher analyzed respondents' answers on inquiry skills questions. Furthermore, the researcher assigned the respondents into the control and experimental groups using the matching variables *pre-level inquiry skills scores*, and *Grade 11 general average*. For three months, learners in the control group were taught using the conventional teaching while those in the experimental group were supplemented with the General Chemistry 1 interactive courseware integrated in the 7E instructional model lesson plan. Prior to learners' mobile phone installation, the said material, crafted as an all-Filipino, locally developed, all-original, and offline-based educational platform available both as web-based and Android-powered mobile application, was validated by the experts. At the end of the experimental stage, the researcher facilitated the post-level inquiry skills test among the learners in control and experimental groups. Lastly, the significant difference between the posttest scores of the two groups was calculated, tabulated, analyzed, and interpreted statistically. A day was allotted for the conduct of focus group discussion and semi-structured interview among select respondents in the experimental group with regards to their meaningful learning experiences in the utilization of interactive courseware in General Chemistry 1 towards enriching their science inquiry skills. Transcripts were analyzed thematically. This will be conducted manually (usually in the initial coding stages up to final coding stages) (Gay et al., 2012) with assistance from the researcher's adviser. These qualitative and quantitative results serve as bases towards the development an enhanced 7E instructional model in enriching the science inquiry skills in General Chemistry 1 which can be observed as follows:

Table 7. Significant Difference between the Control and the Experimental Groups in terms of Post-level Inquiry Skills Score in General Chemistry 1

School	Group	N	Highest Score	Lowest Score	Mean	SD	Mean Difference	t-value	*p-value	Interpretation
A	Control	42	32	5	20.07	5.47	18.70	2.01	0.00	Significant
	Exp.	43	40	35	38.77	1.43				
B	Control	26	39	21	26.46	5.73	11.62	2.04	0.00	Significant
	Exp.	25	40	35	38.08	1.29				
Overall	**Control**	**68**	**39**	**5**	**22.51**	**6.24**	**16.00**	**1.99**	**0.00**	**Significant**
	Exp.	**68**	**40**	**35**	**38.51**	**1.42**				

**Level of Significance at 0.05*

Table 7 shows the analysis of the data obtained where the p-values **(0.00)** of Schools A and B are lower than 0.05 level of significance. This means that the researcher rejects the null hypothesis. Likewise, the overall results reveal a p-value **(0.00)** which is lower than 0.05 level of significance. The researcher has arrived with the same decision. Therefore, there is a significant difference between post-level inquiry skills mean scores of respondents in the control and the experimental groups in schools A and B after the conduct of the study. Hence, the use of interactive courseware integrated in the 7E instructional model is effective in enriching the science inquiry skills of the G12 Science, Technology, Engineering, and Mathematics learners. Furthermore, this indicates that the respondents in the experimental group are able to enrich their science inquiry skills with the use of interactive courseware as supplementary material. It can be noted that science inquiry skills of the learners need to be developed for them to concretize their learning. Furthermore, teachers can act as facilitators guiding learners in discovering concepts which they can use in their everyday situations (Adesoji & Idika, 2015). By using the interactive courseware, the learners were able to have a grasp of the essential ideas needed. The 'aha' moments experienced signifies the satisfaction of curiosity of the learners which eventually develops into higher order thinking. Eisenkraft (2003) reiterated the 7Es phases. Integration of the concept of *elicit, engage, and explore phases* allows the teacher to find the use of 7E instructional model coupled with interactive courseware helpful in deepening every concept learned in the subject. This also connotes the learning becomes more relevant to them as they apply what has been learned in the activities during the discussion. These encompass *explain* and *elaborate phases* of the 7E instructional model. This connotes that logical sequence of the lesson helps the learners in developing their science inquiry skills. Moreover, the learners can easily grasp the connection of each phase leading them to construct knowledge and skills as compared to those who are exposed in the conventional method of teaching. This represents the important part of the 7E instructional model which is the *evaluate phase*. Aside from the formative assessment included in the courseware, the teacher has observed that the learners do not stop studying General Chemistry 1 after class. They find it easy to follow the lessons the following day because they have the material which they can browse even without the internet connection. This connotes that learners develop a study habit and are able to further realize the value of the learned concepts. This complete the 7E instructional model which is the *extend phase*.

Part B. Encapsulating learners' meaningful leaning experiences in the process

This part encapsulates the meaningful learning experiences conceived by the learners during the enrichment process of their science inquiry skills. The use of interactive courseware as 'guide on the side' of learners supplements available learning materials of the teachers in teaching General Chemistry 1 (Stockwell et al., 2015). Prior to the implementation of K to 12 curriculum are the rising problems such as the availability of instructional materials and readiness of the learners to cope up with the challenges of 21st century (Ramirez & Monterola, 2019; Caballero & Cabahug, 2015) that will enhance the inquiry-based learning (Bhagat, 2017; Samaresh, 2017). The meaningful learning experiences are good indicators of a successful teaching-learning process (Üce & Ceyhan, 2019). Based on this notion, the researcher used careful and thorough documentation of the classroom discussion between the respondents in the control and the experimental groups are taken into consideration. It can be noted that those in the control group are taught using the conventional teaching method while those in the experimental group used interactive courseware installed in their mobile phones integrated in the 7E instructional model. Science inquiry skills are categorized as basic, the readily observable ones, and integrated, the one that integrates critical thinking and are not readily observable, in science classes (Turiman et al., 2012). This connotes that integrated science inquiry skills are difficult to assess and can only be acquired through time. Additional ideas of Kazeni et al. (2018) explained that these skills can be promoted using the practical investigations leading to the enrichment of the conceptual understanding among learners to carry out activities based on their own hypotheses.

Asking questions about the real world is the first step in developing one's science inquiry skills. A response about this can deemed, to wit: "*I like advanced study and we don't have available books provided in Chemistry, so it helps me a lot especially when I'm asking questions about the world. It helps me to improve my inquiry skills during the period of time I am using it."* (Student 1B, interview). It indicates that curiosity on what is happening in the surrounding calls for investigation to learn something new. To say: *"The application helps me in hypothesizing and exploring as a learner in a way of adapting its content and everything about the lessons contained in this application. Also, I learned how to apply all the lessons that we learned from this interactive courseware."* (Student 4B, interview)

Hypothesizing is giving one's conviction of what might happen beforehand in an experiment. A series of experiments/activities conducted in General Chemistry 1 was embedded in the interactive courseware. The researcher simplified them according to the availability of the materials, time allotment, and capability of the learners to do so. Moreover, the material provides the learners vast source of information which they can explore thoroughly. After formulating hypothesis, a learner says: "*It helps me a lot when I'm tired to review and accomplish homework. Answers can be found in the phone. It's great because I do not need to spend money. Lastly, the courseware helps us in designing and conducting investigations for us to further understand the concepts."* (Student 8A, interview).

Kazeni et al., (2018) explained that inquiry skills can be promoted using practical investigations leading to the enrichment of conceptual understanding based on learners' crafted hypotheses. Truly, Science encourages the learners to **conduct science investigation** in looking for solutions to problems. This involves easy-to-follow procedures with the tentative answers. The next process is exemplified by the following accounts, to quote: "*Due to its concise and clear presentation of the topics it helps us to classify, predict, and describe the concepts at hand."* (Student 3A, interview)

This is supported with this account:
"The application helps me to enrich the science inquiry skills because every topic has specific descriptions that help me in explaining the concepts. I can easily understand the things that the teacher is discussing." (Student 2A, interview)

The ability to **classify, predict, describe, distinguish the differences, and explain** the concepts are salient features of science inquiry skills (Labouta et al., 2018). Conversely, Gürses et al., (2015) reported that senior high school students are not yet equipped with these science inquiry skills. It might affect their performance when faced with challenges in college. Thus, the researcher used the learning competencies prescribed in General Chemistry 1 to determine the science inquiry skills needed to be enriched among the learners during the course of the study. These skills are embedded in the topics under the different contents which are the limit of the study. Henceforth, the learners were still able to enrich their inquiry skills. This can be noted by saying, *"We can do advanced reading and in validating our answers in the problem solving."* (Student 9A, interview). Another learner strengthened the claim by stating:

"The application helps me in communicating results with the use of its content and design because its content has a lot of formulas and problems that really help me a lot in my problem-solving skills." (Student 8B, interview)

Last but perhaps not the least of these skills that need to be enriched among the 21st century learners is the ability to **validate and communicate the results**. In every inquiry process involves the authentication of the results. This requires critical thinking and rigorous analysis. After such, the results can then be communicated. All of these skills comprise the basic and advanced science process/inquiry skills which are expected to be developed among learners of today. Linking these science inquiry skills to the 21st century can be reflected on these accounts, to wit: "*It has problem solving that helped me practice my problem-solving skills. It has definitions that helped us in our homework and school activities."* (Student 6A, interview)

Imagination has no limits. Hence, learners should be given adequate tasks that will enable them to construct their knowledge and skills. Teaching the learners how to develop their **imaginative skills** enable them to realize the vastness of information and to consider the world as a learning community with the necessary resources for them to grow. Perhaps one of the most important skills to be developed by the learners in order to survive in this world is accounted as: *"The courseware helps me in enriching my science inquiry skills as it provides a lecture that fit the science subject. Also, it provides some experimental activities that improve my science investigative skills. Also, there are different given solutions and formula for solving some scientific mathematical problems that surely help my critical thinking and computational skills."* (Student 3B, interview)

This is added by another experience:
"The application really helped me enrich my science inquiry skills. The courseware involves many analytical problems which helped me develop my analytical and hypothesizing skills. I have also enriched my skill in solving mathematical problems in Chemistry with the help of the courseware." (Student 5B, interview)

Critical thinking and computational skills are two skills needed to be honed among the 21st century learners. Moreover, these skills are vital to certain disciplines like Mathematics, Physics and Chemistry especially when dealing with problem solving. Likewise, learners are expected to develop these skills since they will be dealing with courses which are highly in dire need of them. Belecina and Ocampo Jr. (2018) described critical thinking skill as the use of highly analytical thinking leading to the creation of means to a problem. Hence, these two skills are integrated in the development of the interactive courseware. Lastly, this important skill must be guided properly so as to be used by learners in developing their own meaning, to quote: *"The application helps me in a way that it offers a lot of activities and tasks that strengthen my ICT skills which greatly helps me in understanding deeply all of our lessons."* (Student 8B, interview)

The high demand among teachers, learners, and various educational stakeholders is a challenge that boils down on the manner of ICT integration as part of classroom instruction. This is supported by Mustafa and Fatma (2013) that learners build their own experience by integrating readily available technology learning Chemistry. Moreover, Dewi et al. (2019) supported the idea that ICT-based learning is closely related to essential 21st century skills like collaboration, digital literacy, critical thinking, and problem-solving. Hence, the researcher considered recommendations that learning Chemistry can be better improved through the use of mobile phones, laptop, and desktop as e-learning materials to develop learner's ICT skill.

Phase III. Enhanced 7E instructional model integrated with interactive courseware

Wenning (2011) reiterated that an enhanced model focused on teaching science inquiry skills must be developed based on the intellectual capability and meaningful learning experiences of the learners. Furthermore, it can be noted that approaches used in teaching primary learners are far different to those in the secondary level. The researcher strongly believed that inquiry-based learning is an essential teaching companion to capacitate learner's cognitive and psychomotor prowess by developing the skills necessary to strive in this society. Likewise, careful consideration must be taken to appreciate its beauty. Needless to say, Chu et al., (2016) described inquiry skill as one of the 21st century salient features needed to be developed by the learners in the current society. Remembering the phases previously described and discussed thoroughly led to the final output of this study. The experiences, themes, and ideas collected out of the responses in the focus group discussions and interviews led to the crafting of the enhanced 7E instructional model (Figure 2).

Figure 2. Enhanced 7E instructional model integrating the interactive courseware

The 7E instructional model developed by Eisenkraft (2003) follows a cycle expanding the previous model crafted by Bybee (1997) which promotes continuity of the learned concepts as one progresses in each phase. Based on the initial framework, the learners typically process information based on logical, chronological, and scaffolded instruction. Hence, the learners generally create meaningful learning experiences from previously held beliefs which, in turn, transformed into newly discovered understanding (Miadi et al., 2018). In cognitive structures, this takes some time before realized. Ideally, present generation has various study habit pattern. Few are still reading their books while most of them are depending on readily available information in their handheld devices/gadgets. Moreover, they find it convenient and accessible to gather information when they are used to it. As emphasized in the present curriculum, learning experience is strengthened when learners are encouraged to satisfy their intuitive minds by discovering new things. More so, learners tend to collaborate with their peers when they accomplish tasks. Lastly, in the course of the study the learners and teachers develop 'chemical' bonding as they build healthy classroom relationship with the aid of interactive courseware.

Discussion

In Phase I of the study, the researcher determined the causes of difficulties enriching the learners' science inquiry skills. Serving as the baseline data, this gave the study its foundation to further investigate quantitatively and qualitatively. 1. In general, the *nature of topics, learning environment, learner- and teacher-related issues* were found to be the root causes of difficulty in the enrichment of science inquiry skills among Grade 12 learners in General Chemistry 1. Deductively, learners became effective and efficient in learning their lessons when they applied what is learned in their lives (Chu et al., 2017; Kelley & Knowles, 2016). The use of online open sources in teaching arouse their interest and helps learner to organize thoughts (Williams & Pence, 2011). Likewise, they developed their critical thinking as they solved the chemical problems posed in the interactive courseware. Science, as knowledge and process, is learner-centered discipline where learners and teachers are expected to create an environment driven by the people, for the people (Wenning, 2005). Thus, the powers of collaboration and cooperation are developed in the process. Living in a modern society entails that learners should be indulged to become technologically literate citizens capable of extracting the best possible means from the array of possibilities (Bindu, 2016).

Henceforth, based on the responses of the learners, the researcher described that the mind-oriented and values-oriented learners make up the 21st century learning. These two aspects of human as a person are continuously honed throughout their lives seeking along the way yet they lack the ability to transform these ideas into useful ones. These characteristics of the 21st century learners are accompanied by the multitude of factors identified such as *nature of topics, learning environment, learner-related, and teacher-related issues* (Jocz et al., 2014) which are under the second subtheme. This drives the researcher to pursue the study and produce the necessary impact to the educational needs of the 21st century learners. As an offshoot to the identified problems, the researcher developed a way to innovate an instructional material in Chemistry to address factors that causes difficulties in enriching the science inquiry skills.

In Phase II of the study, the encapsulated meaningful learning experiences were conceived from the learners' responses during the enrichment process of their science inquiry skills. Looking back in the previous years of K to 12 curriculum implementation are the rising problems such as the availability of instructional materials and readiness of the learners (Aggabao et al., 2018) to cope up with the challenges of 21st century hindering the enrichment of science inquiry skills. An idea came in to use the widely available mobile phones as a way to cope up with the learners' needs (Laidlaw & O'Mara, 2015; Williams & Pence, 2011). Thus, an interactive courseware in General Chemistry 1 was designed and developed to address the needs as far as inquiry learning is concerned. Integration of the material in the 7E instructional model is not easy. Yet studies have shown that the use of said model as an effective approach in teaching difficult and complex concepts addresses the causes of difficulties in enriching the science inquiry skills (Iksan et al., 2018; Samaresh, 2017; Eisenkraft, 2003). However, the use of ICT integrated in the model has not been given direct emphasis for years. Ultimately, science inquiry skills are enriched when integration of an interactive courseware (Fu & Hwang, 2018) is implemented with 7E instructional model phases simultaneously.

Based on the researcher's careful and thorough documentation of the classroom discussion between the respondents in the control and the experimental groups, it can be noted that the integration of interactive courseware in the 7E instructional model created an impact in the learning style of learners towards Chemistry. This I supported by the studies of Samaresh (2017), Balta (2016) and Ruggiero and Mong (2015). Moreover, this signifies an innovation of ideas as to how the learner-centered approach could be carried on using the material. This led to the development of fondness among the learners with regards to unraveling the 'secrets' of

Chemistry. Adhering with the constructivist ideas, the interactive courseware welcomed changes happening in the society (Khan & Masood, 2015). Learners were assisted in the process and left to become independent as they construct their own experiences in which they will use in the future (Chu et al., 2016). Likewise, a constructive learner thinks creatively and discovers ways to better understand things (Khalid & Azeem, 2012). Finally, learners connect the ideas they have learned in the past to that at hand in present. This summed up the meaningful learning experiences of the learners with the use of the material integrated in the 7E instructional model.

Inevitably, the factors affecting the science inquiry skills are, by far, the perceived causes of difficulties among the learners and teachers as far as Chemistry is concerned. These, in one way or another, hindered the process of enriching the necessary inquiry learning typically used by learners as science practitioners in years to come. At present, teachers should be vigilant enough to address these issues and create alternative methods along the way. Gone are the days where teachers function as knowledge dispenser while learners are passive receivers of information (Ødegaard et al., 2014). In the current education system, teachers function as facilitator of learning whereas learners are given opportunity to widen their horizon and create deep understanding of the perceived concepts (Faulkner & Latham, 2016; Maeng et al., 2013). In one way or another, this gave the researcher the hope to address the need to continuously improve the inquiry-based learning among the senior high school learners. After all, they are the next generation of professionals who will lead a more progressive and competitive country.

The last phase developed an enhanced 7E instructional model integrating the interactive courseware in General Chemistry 1. The experiences, themes, and ideas collected out of the responses in the focus group discussions and interviews crafted the output the enhanced 7E instructional model. Ultimately speaking, the 7E instructional model is enhanced with the integration of the developed General Chemistry 1 interactive courseware. In turn, the material enriched the science inquiry skills as observed in the learner's responses as well as in their manner of collaboration and participation in the class. The enrichment of these skills created the 21st century learners where they are able to cope up with the ever-changing needs of the society. As 21st century individuals they are geared to enrichment of their science inquiry skills (Havice et al., 2018; Thibaut et al., 2018). In turn, these skills are geared with the use of interactive courseware.

Conclusions

In general, the *nature of topics, learning environment, learner- and teacher-related issues* were the root causes of difficulty in the enrichment of science inquiry skills among Grade 12 learners in General Chemistry 1. The implementation of the 7E instructional model was effective in enriching science inquiry skills of the Grade 12 Science, Technology, Engineering, and Mathematics (STEM) learners. The respondents in the experimental group were able to enrich their science inquiry skills with the use of the interactive courseware as supplementary material in General Chemistry 1. Lastly, the enhanced 7E instructional model was crafted based on quantitative and qualitative data obtained from Phases I and II of the study. Its phases followed cyclic process around the essential elements' *interactive courseware, science inquiry skills,* and *21st century learners.* All of these are produced from the recurring codes *ideal for millennial, interaction,* and *learning experiences.*

Recommendations

Implementation of school remediation and enrichment programs can be done to the identified causes of difficulties in Chemistry as well as in other science disciplines. Likewise, an enhanced 7E instructional model integrated with interactive courseware can be utilized by Science teachers and learners in senior high school. Furthermore, the model can be integrated to other science subjects to promote inquiry-based learning towards the construction of learners' meaningful experiences for lifelong learning. This can be tried out in other science disciplines and even in other subject areas to promote the application of inquiry and constructivist approaches in accordance with the K to 12 Basic Education Curriculum. Lastly, school policies can be drafted to support inquiry-based learning creating an atmosphere of collaborative, and constructive learning.

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Study of Strength and Thermal Characteristics of University Nano-Satellites

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Abstract: This paper presents strength and thermal studies, as well as an analysis of the design material for the development of a nanosatellite model. By using the SolidWorks software environment, an effective solid-state finite-element model of a nanosatellite are developed, on the basis of which the stress-strain state of the nanosatellite is analyzed, as well as the criteria for evaluating the strength of nanosatellite structural elements made of composite materials. The strength reserves are determined, the maximum displacements of the structural elements are found. It is determined that the developed model of the nanosatellite meets the conditions of strength and thermal conditions.

Keywords: Nanosatellite, Spacecraft, Strength, Thermal regime, SolidWorks, Alloy, Solar flow

Introduction

Satellite technologies are of global importance in the social and economic development of the entire state as a whole, and also allow us to raise the information and space support systems of various countries to a high level. Along with large-budget serious devices, there are small ones called nanosatellites. Currently, satellite technology is being developed in miniature sizes and components up to a weight of 1 kg. The nanosatellite belongs to the class of small satellites with a mass of less than 10 kg [1,2].

Within the framework of small satellites, we should mention nanosatellites developed at universities for educational, scientific and technological purposes. The main objectives of these initiatives are:

1. engage students in complex teamwork aimed at designing, developing, and producing a complex product; thus training students ' ability to solve real-world problems;

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2. for in-orbit testing of components and materials intended for ground use in order to reduce the cost of future space missions;
3. demonstrate the feasibility of innovative missions and system concepts [3].

The development and implementation of nanosatellites is one of the most promising areas of engineering and technology in the aerospace industry. Thanks to the continuous evolution, and with the preservation of low cost, small spacecraft (MCA) have become a flexible tool for conducting scientific, educational and technological experiments in outer space [1]. The strength analysis of spacecraft under random loads contains the computational-theoretical and experimental stages. The computational study involves the development of an adequate simulation model (IM) of a spacecraft subject to random vibrations, and the determination of the numerical characteristics of the stochastic stress-strain state on its basis [3].

In this article, we consider the problem of constructing a simplified model of the nanosatellite body and its finite element model for the strength analysis of the structure, and also perform a static calculation of the loading of the nanosatellite body, namely, thermal calculations.

Statistical calculation of the nanosatellite body strength

The resistance of the materials and equipment elements used in their creation to the effects of the surrounding space environment plays a crucial role in ensuring the long-term trouble-free operation of nanosatellites. According to the available expert estimates, more than half of the spacecraft failures and failures are caused by the adverse impact of the space environment [7]. The strength of the nanosatellite body provides additional requirements for the structural materials used in the manufacture of the body, namely:

1. high vibration and impact strength;
2. resistance to corrosion and abrasive wear;
3. high crack resistance at sharp and abrasive temperature changes.

Thus, according to [8], the ultimate tensile strength is an important criterion for any structural material. Figure 1 shows the typical stress-strain curves of four different aluminum alloys in uniaxial tensile tests compared to: -low

1. carbon steel;
2. high-strength steel;
3. titanium alloy.

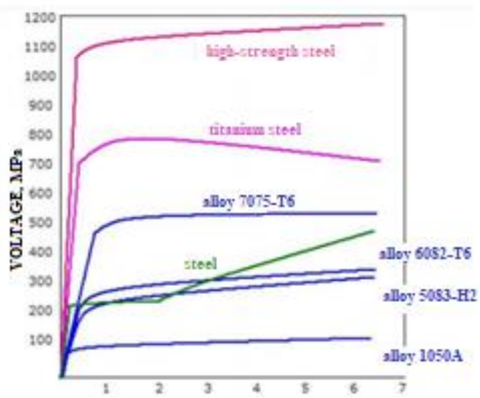

Figure 1. Curves of the stress-strain state of aluminum alloys in comparison with other structural materials [4]

In accordance with [4], with the strength that is achieved per unit mass, dividing the strength by the density, we get a completely different picture (Figure 2). With this approach, the most effective structural material for the model is aluminum alloy 7075, and alloys 5083-H12 and 6082-T6 will be more effective, relative to low-carbon steels.

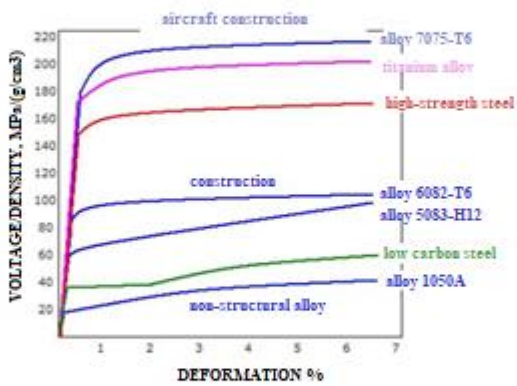

Figure 2. Strength per unit density of aluminum alloys and other structural materials [6]

Under static loads, during tensile testing, the ultimate strength (вb) or yield strength (σ0, 2,тt) - characterizes the resistance of the material to plastic deformation. To approximate the static strength, the hardness of HB is used. For materials used in aviation and space technology, the mass efficiency of the material is important [10].

The experimental sample is an element of full-scale structures of the nanosatellite body in the form of a cube, measuring 100mm*100mm*100mm, made of aluminum alloy with a thickness of 2 mm, the mass of the nanosatellite body is 300 g (see Figure 3).

The digital model is simplified in two stages.

Task of the first stage:

Removal from the model of all elements that do not contribute to the strength characteristics of the model, such as:

- fasteners;
- electronic elements with small dimensions;
- electrical connectors.

The main task of the second stage:

- correction of interference of parts.

Interference is observed for the following reasons:

- build errors of the original model;
- errors in the coupling of electronic components with the boards;
- errors in the holes of the boards.

To determine the force load on the body, the gravity force formula was taken (see formula 1) [5].

$$F = G\frac{m1m2}{(H+R)^2} \quad (1)$$

From here,

$$F = 6{,}67 \cdot 10^{-11}\,\frac{0{,}3 \cdot 5{,}97 \cdot 10^{21}}{(6310 \cdot 160)^2}$$

$$F = 3\ [\text{кН}]$$

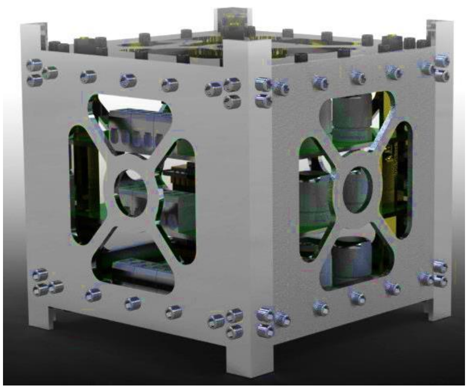

Figure 3. Initial model of the nanosatellite

The preliminary parameters of the nanosatellite body and the impact load were loaded into SolidWorks to determine the strength, see table 1.

Table 1. Parameters for performing calculations in SolidWorks

Load on the housing	**Housing parameters**	
Power-1=3 kN	**Objects:**	31 faces
	Reference:	Edge < 1 >
	Type:	To apply a force
	Values:	3 000 N

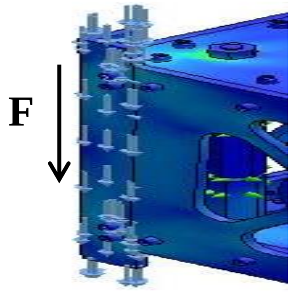

Figure 4. Nanosatellite framework in SolidWorks

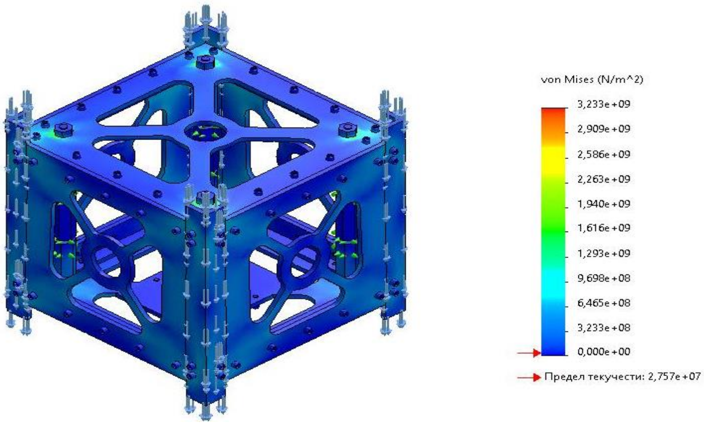

Figure 5. Statistical calculation

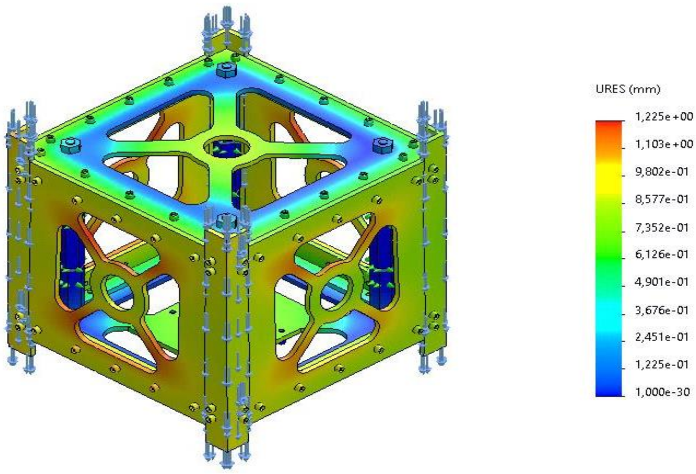

Figure 6. Statistical calculation of the displacement

As a result of this research on the analysis and selection of the most suitable design material for the development of a nanosatellite model, studies of the strength characteristics of aluminum alloys of various grades, a 3D model of a nanosatellite was constructed in SolidWorks. In statistical calculations, the displacement of the frame is equal to-1.225 mm.

Simulation of the thermal regime of a nanosatellite

In flight, the spacecraft is affected by a vast complex of factors of outer space that are different in their physical nature and origin: high-energy electron and ion fluxes, cosmic plasma, solar electromagnetic radiation, meteor matter, solid particles of artificial origin, etc. As a result of such an impact, various physical and chemical processes occur in the materials and elements of the spacecraft's onboard equipment, leading to a deterioration in their operational parameters. Depending on the nature of the processes initiated by the impact of the space environment, the changes in the properties of materials and equipment elements may have a different time scale, be reversible or irreversible, and pose a different danger to on-board systems.

Thermal control Module Objective of the satellite’s thermal control module is to maintain temperature for each module/component within its specified range during all the phases of this mission. In order to save on project costs, the thermal balance in the satellite shall be achieved through passive methods such as thermal coating, use of heat pipes, sunshades, integration of multi-layer insulation etc. The targeted range of temperatures for some of the modules are provided in the Table 2. Thermal design of nanosatellites is discussed in details in one of the current researches [11]. It is also concluded that a basic passive control should be adequate to maintain working temperature ranges for most of nanosatellite components using thermal coatings/tapes [11]. Use of heaters is recommended to keep batteries warm during extreme conditions. Thermal design of a Multi Mission Bus Demonstration (MBD) Spacecraft developed at The Johns Hopkins Applied Physics Laboratory (JHU/APL) is discussed in detail while providing details on the thermal testing performed in [12]. Bulut and Sozbir have proposed a thermal model and later designed a thermal control system of the nanosatellite emphasizing the importance of appropriate surface coating [13].

It is proposed that 80% of the CubeSat area shall be covered by the solar panels and the rest shall be covered by thermal coating. Sources of heat radiations in the Low-Earth-Orbit include, the heat radiated from the Sun, and Albedo or the reflection of solar radiation besides planetary heating from the Earth. During thermal design, Orbital variations in the solar activity shall also be considered. Few challenges are anticipated during thermal design and it will be interesting to analyze and devise newer methods to meet these problems. There shall be difficulties in maintaining required operating temperatures for batteries since they have smaller temperature range compared to other electronic components. The outer structure of the satellite is exposed to most extreme temperatures and therefore requires special considerations. Optical elements and Laser also requires thermal isolation and stable temperature control.

According to the nanosatellite assembly standard [11], the nanosatellite structure has the shape of a cube formed as a result of connecting four frames, six ribs and five solar panels. The power elements of the structure, represented by the ribs, are made of aluminum alloy (D16). The nanosatellite equipment is a set of electronic boards connected by a "bookcase" by means of rigid racks.

Table 2. Range of temperature

Modules	Operating Temperature		Survival Temperature	
	Min., °C	Max., °C	Min., °C	Max., °C
Structure	-45	150	-50	155
Power	0	50	-5	55
Magnetometer	-35	75	-40	80
IMU+GPS	-40	80	-45	85
Camera	0	60	-5	65
OBC	-25	60	-30	65
Antenna	30	70	-35	75

The main method of calculation of the thermal regime is the graphic-analytical method [12]. The task of calculating the thermal regime of a nanosatellite, as a rule, is to determine the temperature and temperature overheating of the components. Overheating of any point or area of the nanosatellite structure is the result of the superposition of the thermal fields of various IT (semiconductor crystals or resistors), so it consists of its own and induced overheating. Its own overheating is determined by the action of the IT located at the i-th point, provided that the other IT is turned off. Induced overheating is caused by the action of all IT, except for the one located at the i-th point.

As is known, the thermal circuit of a functional cell is a parallel connection of the thermal resistances of the boards and their connecting layers [6]. Therefore, the calculation of thermal modes of functional cells is reduced to the calculation of overheating it, located on the Board, in accordance with the thermal model. To obtain the calculation formulas for the construction of thermal models, we take the following data:

1) The altitude of the nanosatellite H=160 km;
2) The satellite's orbit is near-Earth;
3) The effect of various thermal loads on the nanosatellite during flight.

Two cases of operation of the thermal regime were considered:

1) when the nanosatellite is located in the shadow segment of the orbit;
2) when the nanosatellite is located on the solar side of the orbit.

The scheme of the nanosatellite flight in a given orbit for two limiting cases is shown in Figure 7 [4].

Figure 7. Orbital flight diagrams [4]

The calculation of thermal loads is performed for a three-dimensional model of a nanosatellite. The simulation was performed for several orbits in orbit. The thermal state of the nanosatellite was calculated using the Simulation SolidWorks environment. The finite element model of the nanosatellite is built automatically, and the load is applied consistently across all the faces and components of the nanosatellite. The results of the thermal calculation for the case with shadow areas are shown in Figure 8. The results of the thermal calculation for the case without a shadow area are shown in Figure 9.

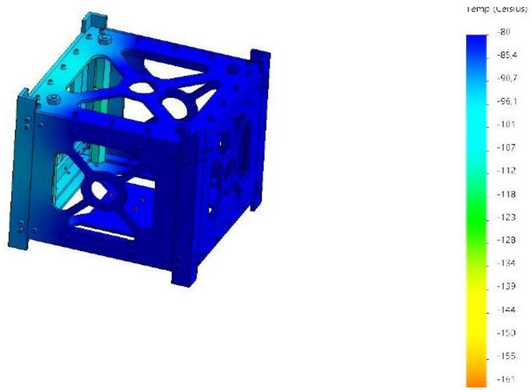

Figure 8. The result of calculating the nanosatellite in the shadow segment of the orbit

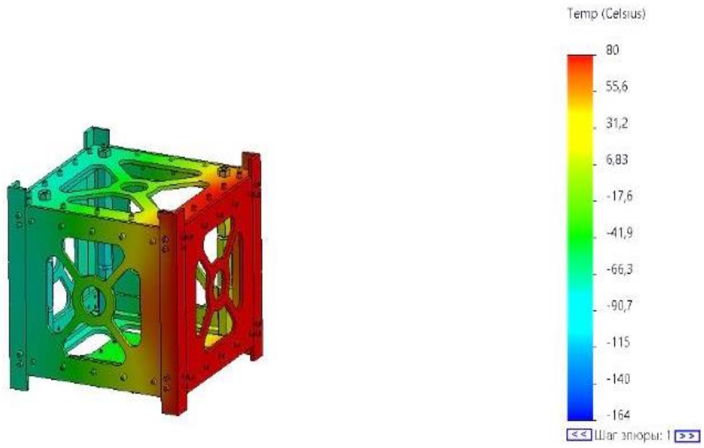

Figure 9. The result of calculating the nanosatellite in the shadow segment of the orbit

As a result, according to the conducted research, the most suitable thermal regime for the nanosatellite in different parts of the orbit was selected. Aluminum alloy is well suited for assembling the nanosatellite frame. It can withstand temperature loads from -80 C to +80 C.

Conclusion

This study will simplify the launch of small spacecraft into space, due to the insignificant requirements for the creation of a nanosatellite design. The analysis of criteria for assessing the strength of nanosatellite structural elements made of composite materials has been carried out. The strength reserves have been determined, the maximum displacements of the structural elements were found. It turned out that the conditions of strength and thermal conditions were met for the nanosatellite. In the SolidWorks software environment, an effective solid-state finite-element model of a nanosatellite was developed, on the basis of which the stress-strain state of the nanosatellite was analyzed.

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Digital Planning Using Building Information Modelling and Virtual Reality: New Approach for Students' Remote Practical Training under Lockdown Conditions in The Course of Smart Building Engineering

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Abstract: The worldwide Corona pandemic has severely restricted student projects in the higher semesters of engineering courses. In order not to delay the graduation, a new concept had to be developed for projects under lockdown conditions. Therefore, unused rooms at the university should be digitally recorded in order to develop a new usage concept as laboratory rooms. An inventory of the actual state of the rooms was done first by taking photos and listing up all flaws and peculiarities. After that, a digital site measuring was done with a 360° laser scanner and these recorded scans were linked to a coherent point cloud and transferred to a software for planning technical building services and supporting Building Information Modelling (BIM). In order to better illustrate the difference between the actual and target state, two virtual reality models were created for realistic demonstration. During the project, the students had to go through the entire digital planning phases. Technical specifications had to be complied with, as well as documentation, time planning and cost estimate. This project turned out to be an excellent alternative to on-site practical training under lockdown conditions and increased the students' motivation to deal with complex technical questions.

Keywords: Smart building engineering, Building information modelling, Virtual reality, Lockdown conditions, Remote practical training

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Introduction

The worldwide Corona pandemic and its consequences on teaching like online lectures and remote exercises had also severely restricted student projects in the higher semesters of the interdisciplinary course "Smart Building Engineering" in Germany. Usually there are practical trainings in the industry intended the 5th and 6th semester of this course to get the students into contact with industry partners for gaining first practical experiences. Unfortunately, it was not possible to implement these plans because of Corona pandemic restrictions.

For not delaying the completion of the studies by missing projects, a new concept had to be developed for projects suitable to actual lockdown restrictions in Germany: There were only online lectures and hardly any students at university allowed for avoiding physical contacts by social distancing. Therefore, it had to be possible to work on the new project from home or with remote access. In addition, it should be a real problem rather than another sample project. The students should be able to apply realistically what they have learned so far in the field of digital planning of smart buildings and technical services.

Method

Current state of the rooms

For creating a new realistic remote project, rooms at the university that had not been used for a long time should be digitally recorded in order to develop a new usage concept as practical training and laboratory rooms for the new course Smart Building Engineering with current plans. Due to the long vacancy and the new requirements, some changes and renovation measures were necessary. The area under consideration consists of several rooms and corridors on two floors (cellar and ground floor). In the first step, an inventory of the actual state of the rooms was done by taking photos and listing up all flaws and peculiarities. The students also had to deal with questions concerning structural contaminated sites such as chlorinated diphenyls or asbestos and entrances to an adjacent air raid shelter from the 1960s that must remain accessible.

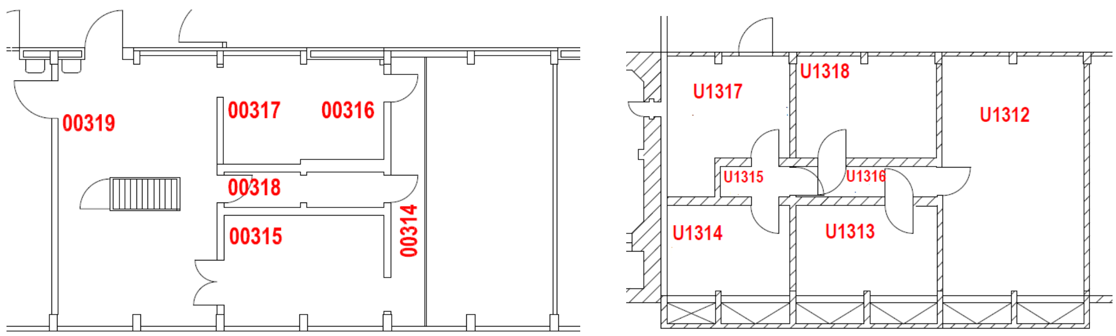

Figure 1. Plans of the rooms on the ground floor (left) and cellar (right), own representation

Workflow in the project and used hard- and software

Since there were no more usable plans for these rooms, a digital site measuring was done with a Leica BLK360 laser scanner by one of the students within one day [1]. In the next step, this recorded data was processed using the Leica BLK360 Manager software to download the raw data from the scanner [2]. These raw data than were processed into point clouds with special reality recognition software Cyclone Register room by room [3]. The software Autodesk ReCap was used for clearing the point clouds [4]. Later on, these data were transferred to the software for planning technical building services Autodesk Revit also supporting the technology of Building Information Modelling (BIM) [5]. All rooms were merged into floors than, so the planning phase could start in a complete three-dimensional model of all rooms together. The Revit plug-ins of the Alpi Caneco software BT 2020 and BIM 2020 were also used for planning and dimensioning of all electrical components because Revit has no option for electrical planning [6] ,[7]. Following, a three-dimensional model was created from the imported data in Revit, in which the complete technical design of components was implemented. In order to better illustrate the difference between the actual and target state, two virtual reality models should be created so that the difference can also be "experienced" with virtual reality glasses by using the software Enscape [8].

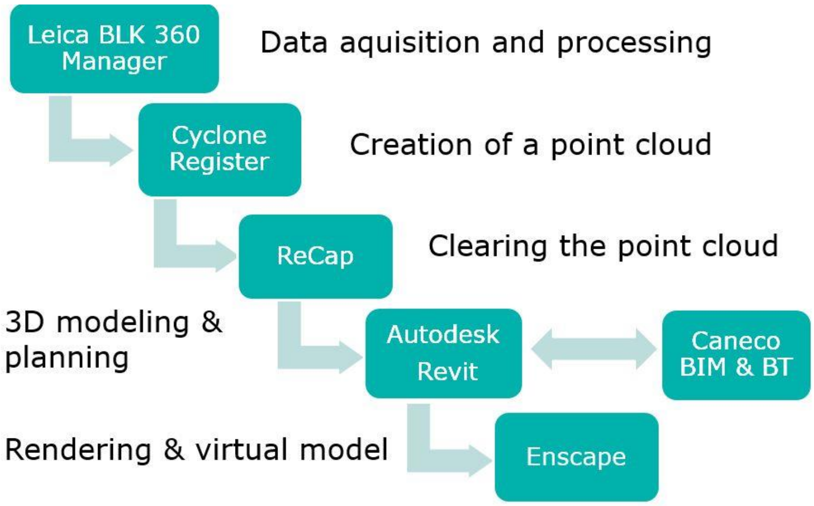

Figure 2. Overview of the workflow, the software used and the work steps, own representation

Results

During the 5 months of the project, the students had to go through the entire digital planning phases. Technical specifications had to be complied with, as well as documentation, time planning and cost estimate. Because of extended corona restrictions during lockdown in Germany at the beginning of 2021, this project replaced the final written exam in this module. Therefore, the project folder had to contain technical documents like circuit diagrams for water and heating, circuit diagrams for electrical components, design calculations and components lists. Construction schedule, construction implementation plan and minutes of meetings with the peer had to be submitted as well.

Figure 3. Example of one of the rooms and the results: Photography of the actual state in the beginning (top left), recorded point cloud data (top right), three-dimensional model for planning purpose in Revit (bottom left) and three-dimensional virtual reality model in the target state (bottom right), own representations.

Discussion

In this project it became obvious, that good computer equipment and a good internet connection are necessary for data rendering because of the high amount of data. Some students had to wait longer for data exchange, model computing and loading of technical components' databases via internet depending on their internet connection. To solve this problem, a remote connection to powerful stationary computers in the university was established and could be used the students in order to handle the big amount of data. In this way all students managed to succeed and set up their three-dimensional models. One example is shown in the following figure 4.

Figure 4. Overview of the target state of all rooms together including furniture and technical equipment, own representation.

Conclusion

This project turned out to be an excellent alternative to on-site practical training especially under lockdown conditions and the students gave positive feedback at the end of the project. It increased the students' motivation to deal with complex technical questions by giving them a real problem. Most students also found it more interesting to independently deal with typical problems during a planning and construction process than simply listening to a remote lecture or waiting for lockdown to end. The possibility of finally being able to "experience" the result as a virtual 3D model via the Internet was an interesting and instructive conclusion to the project for the students. This also helped a lot the visualization of possible mistakes, because they are more obvious in a "realistic" surrounding than on plans and technical drawings.

Recommendations

This type of remote team work could also be an interesting alternative to on-site practical training even after Corona pandemic. The students learnt to struggle planning problems in a more realistic way on their own as it is needed in future jobs. The option to discuss problems or questions with a peer in regular periods was obviously helpful and should be continued in future. This mode of working could be a good training for future working situations in mixed teams in larger companies having people in office, travelling or on the construction site.

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The Cluster Physics Chapter for Thermodynamics Education

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Abstract: Thermodynamics education is not easy both for students and teachers. But the Entropy, Chemical potential, Real gas structure, Fugacity, Molecular interaction, Supercritical phenomena chapters become more comprehensible, if introduced via the pure real gases' cluster physics chapter. A pure gas consists of the only one type of basic particles, therefore, the molar Gibbs energy G is universal for all basic particles. The monomer fraction Gibbs energy Gm logarithmically depends on the monomer fraction density, Dm, which is a perfect argument for thermophysical properties series expansions, named canonical for their correspondence to the fundamental Mass action law. Unlike virial expansions, the n-th canonical expansion coefficient reflects properties of the n-particle cluster. The canonical expansion of various thermodynamics functions, for which precise experimental data may be taken from the NIST Webbook, opens the clusters vision from different points of view. The potential energy of a gas provides the clusters' bond parameters cognition. The bond energy temperature dependence discovers different cluster isomers and the directional bonding. The near critical cluster fractions structure reflects the gas-to-liquid soft structural transition. For students it is useful to develop the canonical series expansion and the cluster structure analysis skills.

Keywords: Computer aided analysis, Pure real gas, Bond energy, Cluster, Molecular interaction

Today's scientists have substituted mathematics for experiments,
and they wander off through equation after equation,
and eventually build a structure,
which has no relation to reality.

Nikola Tesla

Introduction

It is well known that the thermodynamics is difficult both for students and teachers mainly because of the experimental basis weaknesses. For this reason, some thermodynamics notions stay abstract and seem to be artificial. But such sophisticated notions, as Entropy, Chemical potential, Real gas structure, Fugacity, Molecular interaction, Supercritical phenomena become better comprehensible, if teachers introduce them via the pure gases cluster physics basing on the precise experimental thermophysical data. The pure real gas

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platform, based on experiment, is favorable for an advanced thermodynamics education (Sedunov 2020).

A pure real gas is the nearest extension of the widely used in education ideal gas model. Unlike the ideal gas, it includes the molecular interactions, which are the basis of multiple to be studied thermodynamics functions, possessing the largest experimental base. The pure real gas helps to discover the clusters' bond energies.

Unique Features of Pure Real Gases

The cluster physics has a solid experimental basis: many pure real gases have precise databases of their thermophysical properties, like the NIST Webbook (NIST 2021). The pure gases contain only one basic particles type, and for this reason their molar Gibbs energy G is universal for all basic particles (Sedunov 2008), Figure 1. The basic particles of a fluid are particles corresponding to its chemical nature, independently on the cluster structure. The monomer fraction molar Gibbs energy G_m reflects the monomer fraction density, D_m (Sedunov 2008). For an atomic gas $G_m = RT \ln(D_m V_q)$. D_m is a perfect argument for the neat gases thermophysical properties series expansions, named canonical for their correspondence to the fundamental Mass action law (Koudryavtsev 2001). V_q is the basic particles' quantum volume (Kittel 1969).

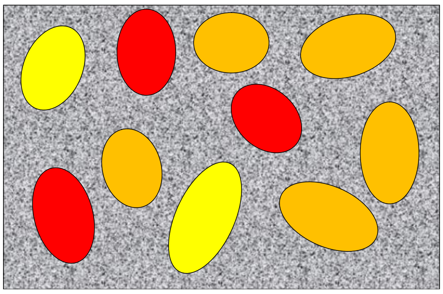

Figure 1. Different clusters (colored figures) in the infinite monomer fraction zone (grey texture) with uniform monomer's density and Gibbs energy (chemical potential).

The monomer fraction zone is filled by uniform density monomers, providing uniform chemical potential. This uniformity results from the chemical equilibrium in the infinite zone. Monomers penetrate in the cluster zones, delivering there the unique chemical potential. In the gas-to-liquid transition at a supercritical temperature we see the reverse picture: liquid fills the infinite cluster zone and monomers fill the pores, Figure 2.

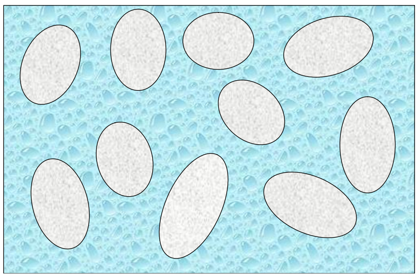

Figure 2. The pores (grey figures) filled with uniform density and unique chemical potential monomers; liquid (blue texture) fills the infinite cluster zone at supercritical temperature and density.

So, the cluster physics explains the Supercritical gas-to-liquid transition!

A very cognitive is the expression for the neat atomic real gas Entropy S (Sedunov 2008): S = H/T - R ln(D_m V_q), where H is the molar enthalpy, T - temperature, R - Universal gas constant; $V_q = h^3 N_A^4 /(2\pi MRT)^{3/2}$ is the molar quantum volume (Kittel 1969) proportional to the cube of the thermal de Broglie wavelength; *h* is the Plank's constant, *M* is the basic particles' molecular mass in kg/mol, N_A is the Avogadro number. This expression extends the Sackur-Tetrode (Sackur 1912), (Tetrode 1912) equation to real atomic gases. For students it is useful to know that this expression differs from the Sackur-Tetrode equation by H/T instead of 2.5R and 1/D_m instead of the molar volume V.

The canonical against virial extension

Unlike virial expansion (Mayer 1977) for pressure - density interdependence, the canonical one is valid for any thermodynamics function, providing the vision of clusters from different points of view. The *n*-th canonical expansion coefficient reflects properties of the *n*-particle cluster, but for virial expansions this option was only silently supposed (Feynman 1972). Finally, this hypothesis has proven to be wrong, because the argument for virial expansions, the total density D, is the mixture of partial cluster densities and the *n*-th virial expansion coefficient has proven to be the mixture of contributions from clusters with different numbers of particles.

Clusters now are considered as a new state of matter (Yarris 1991). This idea seems to be inspired by the Mayer's substitution of the Boltzmann factor exp(-E/kT) on the nonphysical factor (exp(-E/kT) - 1) for clusters and by the virial expansion, which is perfect only for raw experimental data generalization, but in application to clusters ignores the Mass action law. The cluster physics seemed to be so strange, that the specialists in thermodynamics had to agree with these violations of the thermodynamics laws. The contemporary chapters on real gases in almost all thermodynamics manuals contain these wrong statements. The goal of this paper is to build the cluster physics respecting fundamental thermodynamics laws and, on this basis, to find understandable explanations for a number of sophisticated notions.

The Cluster Physics Educational Basis

The working data table creation and extension

We suggest to start the pure real gases cluster physics study after studying the General thermodynamics and the Ideal gas model. The initial experimental data for the computer aided thermophysical data analysis may be downloaded from the US National Institute of Standardization and Technology (NIST) Webbook (NIST 2021). The Webbook permits downloading up to 600 lines of the data table at a time. If a higher data precision is needed, it is possible to download the next part of the table, with a possible change of the step. The most usable data table type is an isothermal with a pressure as a leading column and near zero initial pressure. The isobaric or isochoric versions are also possible. It is a good training for students to create the working data tables.

After the basic data table creation, we add some columns: the D_p = P/RT, D_m, C_{2+} = (D - D_p)/D_m^2, W_{2+} = W/ D_m^2. The zero pressure limit of the C_{2+} gives us the second canonical coefficient C_2 for pressure-density-temperature (PDT) relations, which equals to minus B - the second virial coefficient. Only on the second level we see a correlation of virial and canonical coefficients. The coefficients at higher levels differ enormously.

The clusters' bond energies computation method

The potential energy U of a gas, for which precise experimental data may be taken from the NIST Webbook, provides the clusters' bond parameters cognition (Sedunov 2012). We compute the U values as the difference between the Internal energy Eat a current pressure and at zero pressure: U = E(T, P) - E(T, 0). Then we expand in a series the positive potential energy density W = - UD, starting from a function W_{2+} = W/D_m^2. The zero-pressure limit W_2 of this function is the second canonical coefficient for the potential energy density W. When the W_2 is found we can find the W_3 and so on. The temperature dependences for canonical expansion coefficients W_n provide the *n*-particle cluster bond energies E_n knowledge as the W_n tangents of logarithm dependence on the reverse temperature β = 1000/T,

The bond energies temperature dependences E_n (T) show different cluster isomers (Sedunov 2013) and the atoms with directional bonding. The possibility to find clusters' bond energies and their temperature dependences is the great advantage of the canonical cluster expansion. The change of the E_n values in some range of temperatures means the soft structural transition between isomers of the n-particle cluster fraction. The larger is the cluster's bond energy, the smaller is the transition zone between stable values for E_n. The near critical cluster fractions' bond energies and structure reflect the gas-to-liquid soft structural transition (Sedunov 2013, March). For students it is cognitive to see the difference between the abrupt phase transition in macroscopic systems and the soft structural transition in small systems, like clusters.

The reverse analytical extension method

To extract properties of clusters from experimental thermophysical data it is needed to solve the inverse mathematical problem (Aster 2012), which requires special measures to diminish the input data and processing errors influence on final results (Hoover 1991). For this goal the computer aided analysis should be interactive. The interactive regime permits to change and adjust the processing algorithms to improve the final precision. The input data errors diminishing task is effectively performed by NIST (Frenkel 2012). But a great part of this job is left to researchers, teachers and students, who have to select the best algorithms for their analysis. It is useful for students to develop the canonical series expansion and the cluster structure analysis skills.

Finding the W_n or C_n coefficients requires a high precision of the $W_{(n-1)}$ or $C_{(n-1)}$ determination. For example, a small error in C_2 for Neon results in large errors in initial values for C_{3+}, found as $C_{3+} = (C_{2+} - C_2)/D_m$. The C_2 errors mainly influence on the first C_{3+} values. The more is D_m, the lower are the errors in C_{3+}. To diminish the initial errors in C_{3+}, we use the reverse analytical extension method. We compute the corrected initial values $V(D_{m1})$ basing on the values $V(D_{mi})$ for large arguments D_{mi}: $V(D_{m1}) = 3(V(D_{m(1+k)}) - V(D_{m(1+2k)})) + V(D_{m(1+3k)})$. So, from three values $V(D_{mi})$ spaced on k steps we find the initial value $V(D_{m1})$. For $V(D_{m2})$ we shift our three values on one step forward: $V(D_{m2}) = 3(V(D_{m(2+k)}) - V(D_{m(2+2k)})) + V(D_{m(2+3k)})$. And so on.

The Figure 3 shows the correction of the C_{3+} for Neon at T = 70K by the reverse analytical extension method with k = 32. We see that the corrected line has lower curvature and smoothly joins the initial line after k steps. To apply this method we should use the interactional analysis. In this analysis we estimate the needed value for k and see, if 3k does not fall in the zone of the initial line new curvature. In other words, we select the k value in such a way that three shifted arguments should be in the most stable part of the initial line.

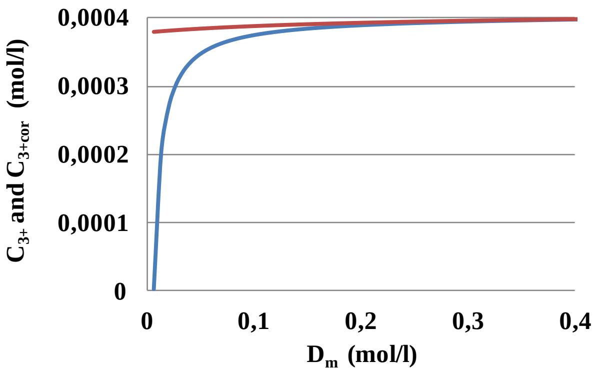

Figure 3. Large errors in the initial C_{3+} values (blue line), corrected by the reverse analytical extension method: corrected values C_{3+cor} (red line).

The reverse extension means that we extend the high stability of the analysis results reached at high arguments to the zone of small arguments, where the errors are most probable. This method is frequently used in our analysis, because the initial parts of curves to be analyzed possess large errors. These errors may be caused by the data discretization, by errors in experimental data, by the data processing. So, the initial parts of curves need a special attention, including the reverse analytical extension method and interactive analysis. These methods may be used by teachers and students.

The Monomer fraction density and Fugacity

To find the monomer fraction density D_m we should solve the differential equation (Sedunov 2008):

$$\partial D_m / \partial P |_T = D_m/(RTD). \qquad (1)$$

This equation coincides with the equation for Fugacity *f*: $\partial f / \partial P |_T = f/(RTD)$ (Lewis 2001). It shows that the Fugacity in a pure real gas is the monomer fraction partial pressure f = RTD_m. The Monomer fraction density is a quite clear notion both for teachers and learners and the fugacity definition on its basis has a clear sense. So, the pure real gases physics gives a clear definition to a sophisticated notion Fugacity!

But the traditional definitions for fugacity are rather vague. Lewis gives fugacity (Lewis 2001) a vague definition through the *escaping tendencies*. Chemical thermodynamics sees "the real gas fugacity as an effective partial pressure, which replaces the mechanical partial pressure in an accurate computation of the chemical equilibrium constant", or as "an analog of pressure that allows to calculate the change in the Gibbs energy as a function of pressure". These definitions are also vague.

For equation (1) the initial condition is: $D_{m\,1} = 2\,D_{P\,1} - D_1$ (Sedunov 2012). And the digital solution (Sedunov 2010) for the equation (1) is:

$$D_{m\,i} = D_{m\,(i-1)}\,(1 + \Delta D_P/(2D_{(i-1)}))\,/\,(1 - \Delta D_P/(2D_i)). \qquad (2)$$

Here ΔD_P is the step value along the column D_P. It is remarkable that the ΔD_P stays both in the numerator and the denominator. The solution (2) is valid also for the Fugacity digital computation. To compute the Fugacity the initial condition could be: $f_1 = 2P_1 - RTD_1$.

Results

The Canonical Coefficients Features

A large interest presents the correlation between canonical coefficients with different numbers. The Figure 4 shows the C_3 coefficient for Neon and its model expressed via C_2.

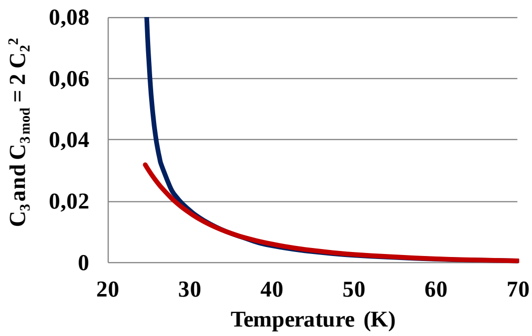

Figure 4. The third canonical PDT coefficient C_3 (blue line) and its model 2 C_2^2 (red line) in Neon.

The model expression was derived for the linear cluster isomer with two bonds. The C_3 coefficient corresponds to this model at T > 30 K. But near the triple point we see a large difference between C_3 and loosely bound linear cluster isomer model. Therefore, at T < 30 K the trimers in Neon have tightly bound isomers, which are responsible for the C_3 coefficient growth.

The Symmetry between Clusters in Vapor and Pores in Saturated Liquid in Normal Fluids

The symmetry between clusters in a saturated vapor phase and pores in a saturated liquid phase of normal fluids (NIST 2021) is demonstrated by the Figure 5. At this figure together with saturated vapor and liquid densities for Nitrogen their sum and the middle line, sum/2, are shown.

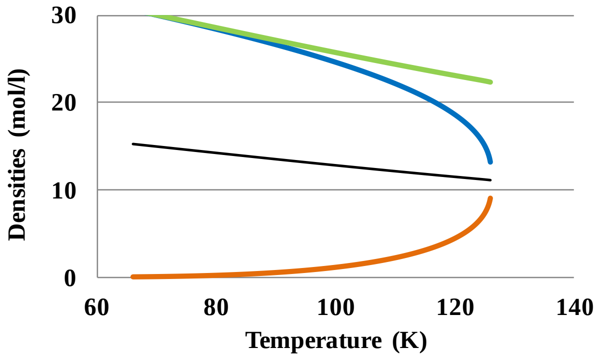

Figure 5. Saturated vapor density D_v (red line), saturated liquid density D_l (blue line) in Nitrogen, the sum $D_v + D_l$ (green line), the middle density (black line).

A similar feature was noticed for: H_2, H_2S, CO, CO_2, F_2, SO_2, and many other fluids (NIST 2021), which may be named as normal. The Figure 5 shows that the saturated densities sum in a normal fluid is a straight line and the middle straight line aims at the critical point. The tangents of slope for D_{sum} (T) for these and some other fluids are shown at the Table 1. There is also shown the linear part share LP as the linear T range to the total (T_{cr} - T_{tr}) range ratio. In normal fluids LP = 1 and in polar fluids LP < 1.

Table 1. The tangents of slope K_{sum} for the D_{sum} (T) straight line part and the linear part share LP.

Fluid	$K_{sum} = dD_{sum}/dT$	$LP = T_{lin}/(T_{cr} - T_{tr})$
H_2	-0,0115	1
CO	-0,0155	1
H_2S	-0,0211	1
SO_2	-0,0217	1
F_2	-0,0265	1
CO_2	-0,0664	1
NH_3	-0,0543	0,99
Ne	-0,0222	0,93
Methanol	-0,0317	0,74

So, in normal fluids we see a mirror symmetry of saturated densities with the middle line as a mirror. It means:

the cluster density in the vapor is equal to the pores density in a liquid at the same temperature in a normal fluid. In polar fluids, as Water and Heavy water, there is no linear part of the D_{sum} graph, Figure 6. The difference between the D_{sum} in the H_2O and D_2O is small. But in the Methanol a long linear part is present, Table 1.

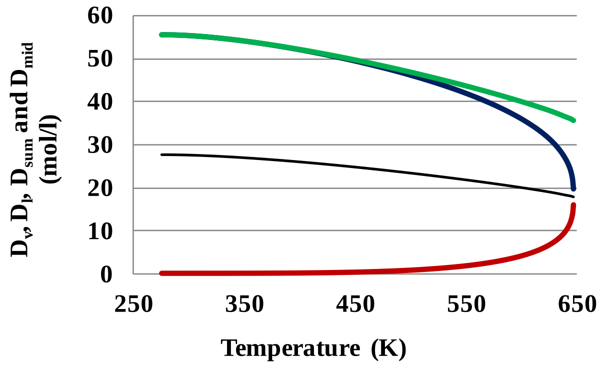

Figure 6. High curvature of the D_{sum} (T) in Water: D_{sum} (green line).

No polar fluid, Neon, (NIST 2021) has a small curvature of the D_{sum} (T) at near critical T, Figure 7. It may be caused by the giant bond energy clusters dissociation.

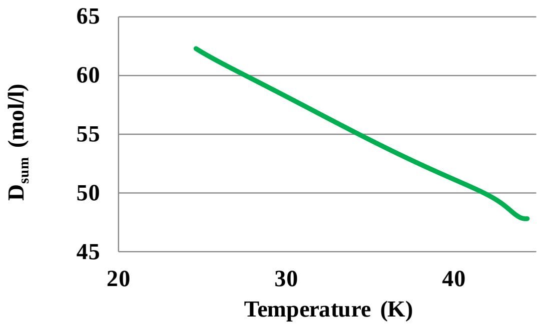

Figure 7. The curvature of the D_{sum} (T) in Neon.

These interesting features wait for their explanation. It is a challenging task for students!

Discussion

In the Results section we have shown only unpublished before results. Their originality tells that the cluster physics can bring a lot of new results. The developed methods of investigations in the cluster physics create a solid basis for this new chapter in thermodynamics. It should motivate the researchers, teachers and students for a deep study and own research of clusters. The canonical expansion creates rich opportunities for new discoveries!

Conclusion

The canonical cluster expansion avoids the virial expansion errors, for this reason it leads to a correct cluster physics and has a large potential for new discoveries.

The pure gases chapter presents not only its own content, but also shows how to solve problems of other chapters in thermodynamics education.

Recommendations

In the real gases study, we should start from pure gases and their remarkable features and to study the cluster physics, basing on precise thermophysical data analysis.

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Teaching the Big Scientific Data Analysis

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Abstract: The contemporary Human activity utilizes huge volumes of digital data to solve efficiently multiple socio-economic, scientific and technical problems. Now the big data analysis is mainly oriented to the socio-economic sphere with a goal to lift the profit. The science and technology to penetrate deeper in the nature of objects and systems under investigation prefer to limit the analysis area, concentrating, for example, only on properties of extra pure materials or isolated systems. In science the analysis should be convergent and the initial data may be and should be regularized to diminish the input data errors. The clusters now are considered as a new or still unknown state of matter. The big thermophysical data analysis appears as the most informative way to discover the properties of clusters in pure real gases, because the continuous spectrum of bound states in clusters prevents from the spectroscopic way for clusters' properties evaluation. The goal of the paper is to teach the main principles of the scientific regular data convergent analysis basing on the author's experience to extract clusters' properties in pure real gases from regularized experimental thermophysical big data.

Keywords: Big data analysis, Regularized data, Convergent analysis, Cluster, Molecular interaction

To understand the actual World as it is,
not as we should wish it to be,
is the beginning of wisdom.

Bertrand Russell

Introduction

Various kinds of the Human activity now utilize huge volumes of digital data (Mayer-Schonberger 2013) to rise efficiency in social, economic, political, healthcare, environmental, scientific and technical problems resolution. It launched the Big Data technology, which includes the collection, analysis, and visualization of vast amounts of digital information (Smolan 2012). To extract from the big data useful knowledge and insights a large attention is paid to the computerized big data analysis development (Maheshwari 2014). Now the big data analysis is in a large extent oriented on profitability of the socio-economic sphere. In this direction large perspectives are waited from the Artificial Intellect and Machine Learning technologies (Cielen 2016), which

Sedunov, B. (2021). Teaching the big scientific data analysis. In M. Shelley, W. Admiraal, & H. Akcay (Eds.), *Proceedings of ICEMST 2021--International Conference on Education in Mathematics, Science and Technology* (pp. 134-146), Antalya, TURKEY. ISTES Organization.

are supposed to support the decision making in multivariate situations.

The Scientific Big Data Analysis

In contrast to the socio-economic sphere, in the science and technology researchers to penetrate deeper in the nature of objects and systems under investigation used to limit the area of the analysis, concentrating, for example, only on properties of extra pure materials or isolated systems. For this task the interactive computer aided analysis (Sedunov 2012) seems to be more effective than the direct computer programming for the final result. In this approach the computer is not the main solver, but an effective adviser, providing intermediate and final results in an informative visual form. In the scientific analysis the initial data may be and should be regularized, thus diminishing the input data errors. The raw experimental data regularization means their critical evaluation to remove the data poorly convergent with the bulk of data and the data interpolation to remove large occasional deviations from the general trend (Frenkel 2012). A good example of a huge collection of regularized scientific experimental data present the US National Institute of Standardization and Technology (NIST) electronic databases of pure materials thermophysical properties, such as the Webbook (NIST 2021) or the Database (NIST 2013). The Database provides the second and the third virial coefficients for selected pure gases used in the Semiconductor Industry. The Webbook contains data for 75 pure substances of various types, the convergent analysis of which permits to penetrate in the nature of clusters and molecular interactions (Sedunov 2012). Unlike the paper Handbooks, the Webbook provides an optimal steps selection and up to 12 decimal digits in presentation of data.

The convergent analysis means:

- a mutual correspondence of raw scientific experimental data collected from all World;
- a correspondence of the regularized experimental data to universal polynomials;
- a correspondence of the processing mathematics to the physical nature of values;
- a correspondence of the individual models to the general physical picture of the Cluster World;
- the data processing with account of the thermodynamics correlations between different values.

The hidden parameters extraction from big experimental data

The main task of the big data analysis in science is to understand and evaluate the hidden mechanisms, governing the behavior of complex systems. The blind spot in thermodynamics are clusters, which are considered as a new state of matter (Yarris 1991), or to be more exact, still unknown state of mater. Their detailed investigation is important both for science and technology. For clusters cognition it is essential to build realistic and comprehensive models of molecular interactions. The main task of the big data analysis in thermal physics of real gases is to extract from experimental thermophysical data the parameters of clusters and molecular interactions. This task becomes much more realizable for pure gases; therefore, we start our analysis from extra pure gases. The hidden parameters extraction from experimental data is known as an inverse problem

(Aster 2012), which results strongly depend on the initial data and processing accuracy: small errors in initial data turn out to be huge errors at the finish. And the data processing methods should correspond to the physics of systems under investigation. So, the convergent processing of raw experimental data is a very important operation for the scientific analysis to be successful.

The goal of this paper is to describe the main principles and the possible traps of the convergent scientific big data analysis basing on the author's experience in the clusters' properties and molecular interactions extraction from regularized experimental thermophysical big data for pure real gases. The possible traps result from misunderstandings of the cluster physics. So, the deeper is penetration in the cluster physics, the more correct are the data processing methods. Some of these principles and the recommendations how to escape from possible traps may be extended to other scientific and technical fields.

Method

A rich structure of pure real gases filled with multiple cluster fractions opens ways for statements of new relations and introduction of still unknown variables. Among these statements a very important is: the n-particle cluster fraction, including the monomer fraction, in a pure real gas behaves as an ideal gas:

$$P_n = RT\, D_n, \qquad (1)$$

where P_n and D_n are partial pressure and molar density of the n-particle cluster fraction, with n = 1 for monomers. The second statement is: in a pure real gas the basic particles' molar Gibbs energy is the same for all clusters and monomers! The basic particles of a fluid are particles corresponding to its chemical nature. Their molar density D is shown in the thermophysical databases, as the fluid total density. In a neat fluid we have only one type of basic particles and one chemical potential G for its basic particles. The third statement is: the total pressure P and the integral molar density of all free moving particles (clusters and monomers) $D_p = \Sigma D_n$ correspond to the ideal gas law: $P = RT\, D_p$.

The most effective and informative variables selection

For the computer aided analysis of pure fluids' precise thermophysical properties it was important to select the adequate method and the most informative variables. For equilibrium clusters concentrations, as for chemical compounds, the fundamental Mass action law **(**Koudryavtsev 2001) is valid, and its proper utilization may bring valuable results. To use this law, we recommend the series expansions of thermophysical values by the new variable - the monomer fraction density (MFD), D_m (Sedunov 2008):

$$D_n = C_n\, D_m^{\,n}, \qquad (2)$$

where Cn is the apparent equilibrium constant for n-particle complexes, including real and virtual clusters. The virtual clusters are not bound by the attraction forces, but appear in series expansions due to repulsions. Only D_m, as an effective argument for series expansions, provides the correspondence of the n-th expansion term to properties of the n-particle complexes: including bound by attraction forces clusters and instant colliding complexes. For this reason, the series expansion (2) may be named canonical.

The monomer fraction density

In pure real gases the variable D_m means an average molar density of basic particles, temporarily not bound in clusters. This definition is rather vague, but the D_m can be defined by the phenomenological way via the molar Gibbs energy G named also as the chemical potential of basic particles. In the chemical equilibrium the chemical potential for all basic particles G is equal to the chemical potential G_m of monomers (Sedunov 2008):

$$G = G_m = G_{int} + RT \ln (D_m V_q). \qquad (3)$$

The G_{int} is the part of G connected with internal movements of basic particles: molecular rotations and vibrations, $V_q = h^3 N_A^4 /(2\pi MRT)^{3/2}$ is the molar quantum volume (Kittel 1969) proportional to the cube of the thermal de Broglie wavelength; h is the Plank's constant, M is the basic particles' molecular mass in kg/mol, N_A is the Avogadro number, R is the universal gas constant. From the Equation (3) we come to the differential Equation for D_m (Sedunov 2008):

$$\partial D_m / \partial P |_T = D_m /(RTD). \qquad (4)$$

The Figure 1 shows the D_m in comparison with D and D_p = P/RT. The D_p means the integral molar density of all free moving particles: clusters and monomers. For the differential equation (4) numerical solution we have found an original expression (5) containing the differential ΔD_P both in the numerator and the denominator:

$$D_{m\,i} = D_{m\,(i-1)} (1 + \Delta D_P /(2D_{(i-1)})) / (1 - \Delta D_P /(2D_i)). \qquad (5)$$

As an initial condition, we suggest: $D_{m\,1} = 2 D_{P\,1} - D_1$. For this condition to be precise the initial pressure P_1 should be in the ideal gas zone.

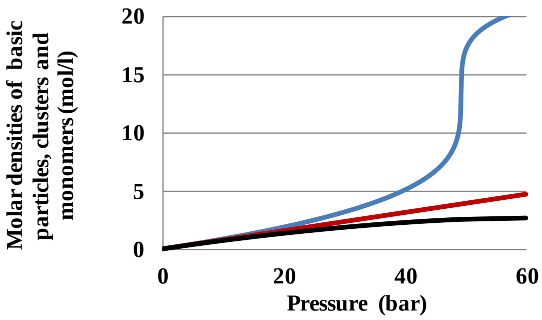

Figure 1. Molar densities of all basic particles D (blue line), free moving particles D_p (red line) and the monomer fraction D_m (black line) in Argon at a supercritical temperature, T = 151 K.

The Figure 1 shows that at pressures over 10 bar the three lines diverge and near critical pressure the total density D quickly grows due to the growth of the clusters number and the number of particles in them. If we remove the MFD from D and D_p, we find the total density of basic particles contained in the cluster fractions ($D - D_m$) and the molar density of clusters, as free moving particles ($D_p - D_m$), Figure 2.

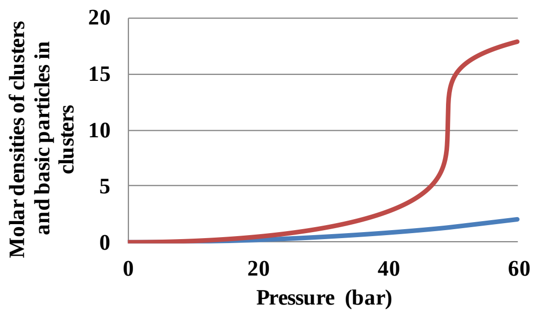

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Figure 2. The total density of basic particles contained in clusters ($D - D_m$) (red line) and the molar density of clusters ($D_p - D_m$) (blue line) in Argon at a supercritical temperature, T = 151 K.

The difference between two lines quickly grows near critical pressure, demonstrating growth of the particle numbers in clusters. The ratio ($D - D_m$) to ($D_p - D_m$), shown at the Figure 3, demonstrates the average number of basic particles in a cluster.

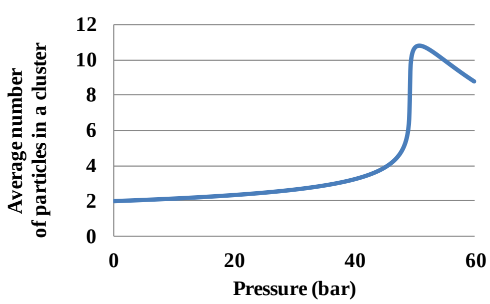

Figure 3**.** The basic particles average number in an Argon cluster at a supercritical temperature, T = 151 K.

We see that there is a wide range of pressures, where dimers dominate and a wider range, where the average number of basic particles in a cluster is under three. But then the average number of particles in a cluster quickly grows. We should not take the average numbers for maximal reachable ones. It may be shown that the maximal numbers can overcome 1000. At supercritical pressures the average number of particles in a complex starts falling. But this complex is not a cluster, but a large pore in the infinite cluster of the liquid-like fluid (Sedunov 2013, March). So, the MFD may be found from known isothermal data for total pressure P and total density D of basic particles and used for the clusters' properties analysis. And the MFD based cluster expansion corresponds to the Mass action law! Due to this remarkable feature the neat equilibrium fluids stay as an adequate platform for clusters and molecular interactions investigation and as an advanced platform for thermodynamics and molecular physics education (Sedunov 2020).

The apparent PDT equilibrium constants

The figure 4 shows the Pressure-Density-Temperature (PDT) interaction function $C_{2+} = (D - D_p)/D_m^2$ to be expanded in a series by D_m.

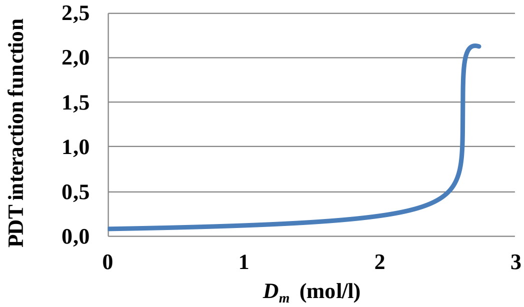

Figure 4. The Pressure-Density-Temperature (PDT) interaction function $C_{2+} = (D - D_p)/D_m^2$.

To compare our analysis method with the theory of virial expansion (Mayer 1977). we consider the PDT cluster expansion. Its theory is reflected in equations (1-5). Only the second coefficient C_2 reflecting dimers' PDT relations is equal to - B - the second virial coefficient. The figure 1 helps to understand why C_2 has an opposite sign to B: C_2 results from the expansion of D_p by D_m, which is smaller than D_p, but B follows from the expansion of D_p by D, which is larger than D_p. The figure 5 shows the $C_2(T)$ changing sign at the Boyle point. It shows that at this point the real dimer fraction becomes weaker than the virtual one.

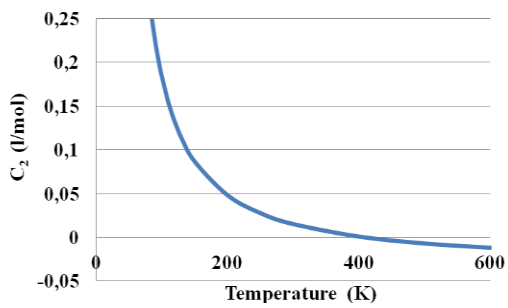

Figure 5. The temperature dependence of the apparent equilibrium constant for dimers in Argon.

The Figure 6 demonstrates the found C_3 coefficient coincidence with its model expression $C_{3mod} = 2C_2^2$. The physical sense of the model expression is: the trimer is formed by forming one of two new dimers around an existing dimer. It gives the factor 2. The same pair interaction apparent equilibrium constants C_2 for old and new dimers tell about an open linear structure of the trimer isomer in this case. So, the big data analysis gives not only quatitative measure of the $C_3(T)$, but also the structure of the formed trimer.

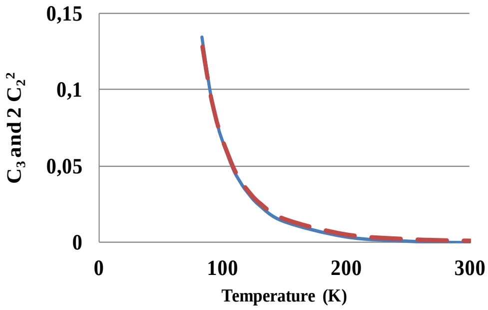

Figure 6. The coincidence of the C_3 (T) (blue line) with its model $2\ C_2^2$ (red dashed line) in Argon.

The $C_3(T)$ deviation from the linear model would say about the soft structural transition to the closed triangular trimer structure. The possibility to express the C_3 via C_2 and the perfect coincidence of the physically clear model $2\ C_2^2$ and real function C_3 (T) in a wide temperature range witness in favor of the canonical cluster expansion, while the virial expansion does not provide the B_3 correlation with B_2. It results from a wrong argument D for virial expansion, being the sum of the clusters' basic particles partial densities. The equation (2) tells about the Mass action law, if D_m serves as an expansion argument, but with D as an argument we never come to the Mass action law. So, a wrong argument D in virial expansions resulted in the fundamental Mass action law ignoring.

The fluid potential energy

To find the clusters' bond parameters we introduce another informative variable - the fluid potential energy (Sedunov 2012):

$$U = E(T, P) - E(T,0), \qquad (6)$$

where E(T, P) and E(T,0) are molar internal energies at the pressure P and zero pressure, correspondingly. We expand in series by D_m the positive potential energy density: W = - UD. The n-th terms W_n of this expansion give the corresponding contributions of n-particle complexes to the total potential energy density W (Sedunov 2013).

The fluid potential energy-based cluster analysis

The $ln\ (W_n(T))$ provide estimations of clusters' bond energies via the tangents of lines slopes, figure 7. For dimers the estimation of E_2 in K coincides with its estimation through the constant volume heat capacity C_v and molar internal energy $E(T, P)$: $E_2 = -\ limit\ \partial C_v / \partial E|_T$. A correlation of two different big data analysis methods confirms both methods.

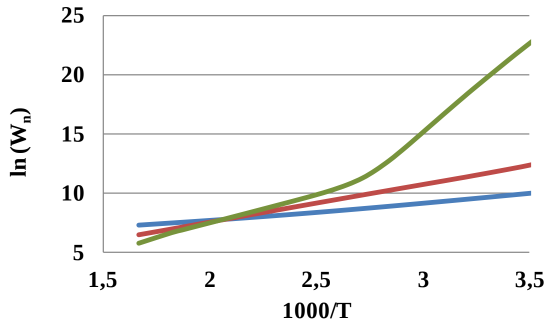

Figure 7. The graph for the Water vapor clusters averaged bond energies estimation: dimers (blue line), trimers (red), tetramers (green).

Results

The soft structural transitions discovery

The bond energies E_n at the figure 7 are determined by tangents of the corresponding lines slope. For Water clusters bond energies E_n are shown at the Table 1.

Table 1. Water vapor n-particle clusters bond energies En averaged for T: T1 < T < T2

n	2	3	4	5
T_1 (K)	274	274	274	390
T_2 (K)	378	600	350	600
E_n (K)	1647	3299	14742	4926

The results at the Table 1 show that $E_n \sim (n - 1) E_2$ for trimers in the whole investigated temperature range but for tetramers only at $T > 390$ K. The bend of tetramers' graph in the temperature range 350 -390 K shows the soft structural transition from tightly bonded tetramers at $T < 350$ K to loosely bonded at $T > 390$ K. A similar transition was noticed also in the tetramers of Methanol. But in Neon the coexistence of normal trimers with giant bonds trimers was discovered.

Linear and 3D clusters in noble gases

The bond energies E_n in the noble gas Helium E_n grow with the numbers n of particles in small clusters linearly: $E_n = E_d\ (n - 1)$, where E_d is the dimers' bond energy, figure 8. The teacher should explain the difference between open linear and closed structures of clusters.

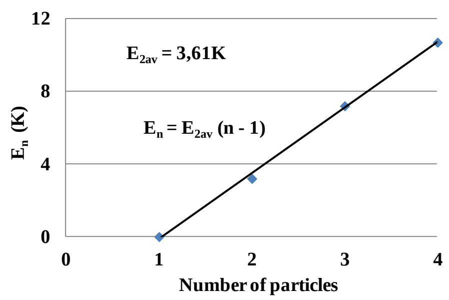

Figure 8. The linear Helium small clusters' bond energy E_n dependence on the number *n* of particles in a cluster.

But in Argon for clusters with numbers *n* of particles from 2 to 5 we see a quasi-parabolic dependence of E_n / E_d on *(n - 1)*, figure 9. The found E_n / E_d ratios are close to 1, 3, 6, 9 values. The corresponding numbers of bonds may be prescribed to dimer, 2D closed triangular trimer, and 3D clusters: tetramer and double tetramer. So, the bond energies estimations show the clusters' structures.

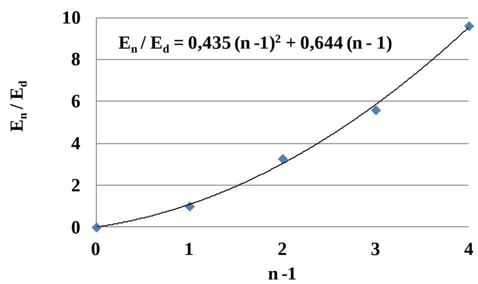

Figure 9. The quasi parabolic bond energy E_n dependence on the number *n* of particles in an Argon cluster.

The linear E_n / E_d dependence on the *n* for Helium origins from the spherical symmetry of the atoms' electron shells, resulting in a linear chain structure of clusters. But the parabolic dependence for Argon tells about directional bonding of atoms, resulting in the tightly bonded clusters. The E_n / E_d estimation for Argon shows the role of the electron shells structure in the directional bonds formation. So, the computer aided big data analysis in the physics of clusters may act as the computer tomography, showing the nanosized clusters' structures (Sedunov 2013, March) instead of the short wavelength spectroscopy, which could destroy clusters with small bond energy.

The traps in the thermophysical data analysis

The raw experimental data contain two sorts of errors: random and systematic. The random errors can be reduced with the interpolation by high order polynomials. But at the polynomial type selection the teacher should take into account the natural laws, which rule the system under investigation. Otherwise the generalization may lead to wrong data, as it happened with viscosity data for Xenon, figure 10.

The erroneous viscosity data for Xenon

To study the viscosity η density dependence we use the value $V_{vis} = \partial(\eta/\partial D)|_T / \eta_0$, which may be named as the characteristic viscosity volume. Here η_0 is the zero-pressure viscosity. The V_{vis} dependence on pressure is shown at the figure 10 for Xenon and Krypton. The viscosity data have been taken from the Webbook (NIST 2021). We see that V_{vis} for Krypton behaves quite naturally, but V_{vis} for Xenon shows unnatural growth in the ideal gas zone. This error contradicts with the theory, which states that the ideal gas viscosity does not depend on density.

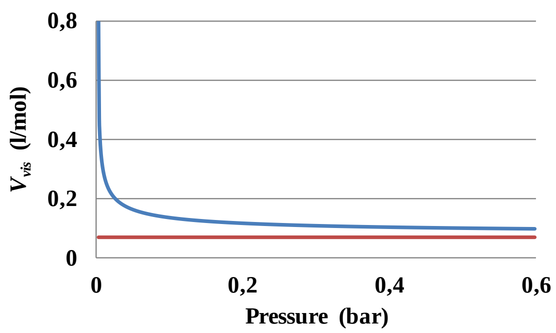

Figure 10. The characteristic viscosity volume V_{vis} dependence on pressure for Xenon at 180 K (blue line) and Krypton at 150 K (red line).

A wrong utilization of universal constants

The universal constants, such as the Universal gas constant R, are regularly updated. But the data in databases reflect their value for the moment of data generation. So, to analyze the scientific data the teacher should find the apparent constant value, for example, R_a as the zero-pressure limit of P/TD, figure 11. For different gases in the Webbook (NIST 2020) R_a may differ. For Helium R_a = 8,3148 J/(molK), for Argon R_a = 8,31451 J/(molK). So, to escape from this error we should for every gas find its own R_a value.

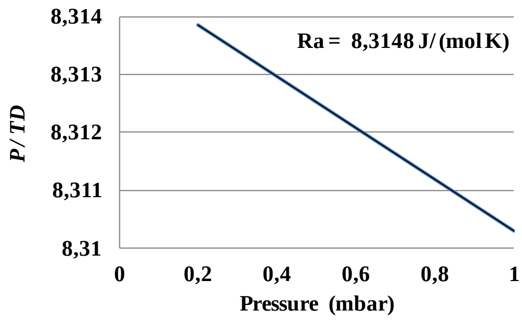

Figure 11. Estimation of the apparent gas constant R_a for Helium data from the NIST Webbook (NIST 2021).

Discussion

Wrong utilization of the virial cluster expansions

The virial expansions perfectly help to regularize raw experimental data. But their utilization to investigate clusters' properties (Mayer 1977) does not correspond to the Mass action law (Koudryavtsev 2001) and gives erroneous results. Feynman wrote (Feynman 1972) that the virial approach silently supposes that the virial expansion n-th term corresponds to the n-particle cluster properties. But it is not so! The expansion terms with $n > 2$ collect contributions from different cluster fractions. And Feynman concludes that the virial cluster expansions program was stopped (Feynman 1972). The next shortcoming of the virial cluster expansion is in its concentration only on the PDT relations, which do not give the clusters' bond parameters.

Wrong interpretation of virtual contributions in the expansion coefficients

To explain the change of sign in the second virial coefficient a new factor: ($exp(-E/RT)$ - 1) was introduced (Mayer 1977). This factor excludes the Boltzmann law application to clusters and builds a boundary between clusters and chemical compounds. But the (-1) addition to the Boltzmann factor results from virtual contributions, being inevitable at series expansions of experimental data. So, the Boltzmann law is valid for clusters, but we should understand the virtual nature of the apparent equilibrium constants falling in the negative zone. The teacher should be ready to meet the revolutionary concepts, such as the virtual cluster.

The Lennard-Jones model limits

The spherical symmetry of atomic interactions in the widely used Lennard-Jones model (Lennard-Jones 1924) results from a simplified vision of the electron shells. For noble gases the spherical symmetry was confirmed only for Helium and explained by the spherical symmetry of its s-type electron shells. All other noble gases demonstrate the directional bonding near the triple point. And trimers in Neon possessing giant bonds run away from the Lennard-Jones model. It shows a significant role of quantum effects in atomic and molecular interactions. The teacher should see and explain students the obsolete theories and their ranges of application. So, the big scientific data analysis opens new and promising directions for research!

Conclusion

The computer aided analysis of big regular thermophysical data results in fundamental discoveries:

- the monomer fraction density based canonical type of the cluster expansion, as an opposition to virial expansions;
- unknown before bond energy values for different gases, temperatures and cluster isomers;
- a new concept of the soft structural transitions in the cluster fractions;

- apparent equilibrium constants for combinations of real and virtual clusters;
- directional bonding in noble gases, rejecting the Lennard-Jones model.

No trivial results of the big scientific data analysis in the real gases thermal physics confirm the validity of its main principles. The found principles of the big data analysis may be transferred to other scientific spheres.

Recommendations

- In the big data analysis teaching we should see the difference between socio-economic and scientific spheres.
- The initial data for the big data scientific analysis should be regularized: they should be carefully selected to remove the outstanding data; they should be interpolated with polynomials, reflecting scientific relations.
- The teacher should select the data processing mathematics, which reflects the scientific relations.
- The teacher should be able to introduce and teach new variables and new concepts.
- The teacher should be able to revise traditional theories and to escape from traps in the analysis.

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Computer Engineering Students' Views on Educational Use of YouTube Videos

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Abstract: Web 2.0 technologies have led to the development of social media platforms that enable users to produce and share their own content. YouTube is such a platform where people can deliver their video clips as well as watch and interpret what others have developed. This study aimed to reach the opinions of the computer engineering students about their YouTube usage profiles and the educational use of the videos published in YouTube. It was designed as a survey research. The sample included 100 undergraduate students from a state university in Turkey. According to the findings, most of the participants access the internet primarily from smart phone and interact with the internet for an average of 6.4 hours a day. The participants stated that YouTube was the most used social media (72%), they subscribed to channels that produce educational content (84%) and watched educational videos (99%). They use YouTube mostly for entertainment (84%) and academic (67%) purposes. They believe that YouTube videos have educational functions such as repetition, compensation, individual learning opportunities, and preparation for exams. No significant differences were found in students' views according to gender and grade level.

Keywords: Web 2.0, YouTube, Educational use, Engineering students, Opinions

Introduction

It has been observed that day-to-day development of technology affects education as well as affecting many other sectors. In today's world where science and technology are developing rapidly, it is no longer possible to transfer and memorize knowledge with traditional teaching methods (Yavuz & Coşkun, 2008). With the developing technology, it is necessary to train qualified manpower to be needed and to integrate new technological knowledge and experience into education (Öztürk & Akgün, 2012). Therefore, many educational institutions have sought to design and implement new models that will meet the needs of students of 21st century (Klopfer & Ark, 2009).

Sagbas, O. F. & Koc, M. (2021). Computer engineering students' views on educational use of YouTube videos. In M. Shelley, W. Admiraal, & H. Akcay (Eds.), *Proceedings of ICEMST 2021-- International Conference on Education in Mathematics, Science and Technology* (pp. 147-154), Antalya, TURKEY. ISTES Organization.

Web 2.0 technologies have increased the relationship between technology and people in an interactive way (Alp & Kaleci, 2018). Unlike Web 1.0 technology, Web 2.0 technology enables users to upload, produce, share and discuss information. It supported to the emergence of social media, which joined the social networks in which individuals are naturally included (Arklan ve Rençber, 2017). It has taken its place as the most original, strongest and popular communication channel presented by the new media within the framework of its own qualities (Göker, 2015). Studies show that people use social media for a variety of purposes such as research, collaboration, communication, sharing content, and entertainment (Usluel, Demir & Çınar, 2014).

Video sharing sites, which emerged from the idea of sharing motion pictures created by people with their own means, gained a popular place with the ability to search and display videos for site visitors all over the world (Emiroğlu, 2007). Founded by Chad Hurley, Steve Chen and Jawed Karim, YouTube is one of the most popular social media platforms, where users share videos, watch and comment on videos (Alleyne, 2008; Yıldırım & Özmen, 2011). Web 2.0 technologies such as Blog, Wiki, YouTube create new demands on learning and provide new support to learning (Duffy, 2009; Flynn-Wilson & Reynolds, 2021; Kelley, 2021; Shukla & Mcinnis, 2021; Yerdelen, Osmanoglu, & Tas, 2019). YouTube can help educators teaching information from all parts of the world using videos as a pedagogical resource (Duffy, 2008). Unlike other social media platforms, YouTube has a network structure that tries to support users to learn from each other (Skiba, 2007). At the same time, it creates a virtual library environment by providing users with access to many videos (Conway, 2006). The aim of this study is to reach the opinions of the computer engineering students about their YouTube usage profiles and the educational use of the videos published in YouTube.

One can subscribe to video sharing sites and upload their own videos as well as watch all videos without signing up (Bostancı, 2010). YouTube can be either visited as a website or installed as an application on operating systems used by mobile devices. When users get an e-mail account from the e-mail services such as Google Company, they automatically get an account from YouTube. As a result of literature review, it is seen that YouTube is not used for a single purpose but rather for a variety of purposes including increasing the knowledge and experience, evaluating their free time, following the popular, producing and sharing own content, interacting with other people, having fun and so on (Arklan & Kartal, 2018).

According to statistics by Alexa (2019), YouTube is the most visited social media site in Turkey just like in all over the world. An infographic data by Social Media Today shows that as June 2019 Youtube has more than 1.9 billion active users per month and over one billion hours of video are watched on YouTube every day (Daneghyan, 2019). Youth Insight, which conducts research on youth, carried out a study to investigate the behavior of young people on social media and to define the dimension of the relationship they establish between them. The study sampled 1000 participants from 7 geographical regions, 500 of which were high schools and 500 universities and showed that participants spent 50 hours a week (25 in weekdays 25 in weekend) on social media (MediaCat, 2011). YouTube is active in more than 91 countries and is the world's second largest search engine as well as the site with the most network traffic after Google (İçözü, 2019). All these statistics show the popularity of YouTube in the world. When looking at the demographic characteristics of the users in 2019, more than 50% of the YouTube viewers are women, 59% of the users between the ages of 16-24 increased their use of YouTube compared to 2018, and 46% of the users between the ages of 25-34 (İçözü, 2019).

Video is the most important tool to provide records for events that take place, and to review and analyze these records repeatedly (Tan & Towndrowb, 2009). YouTube provides educators with a pedagogical resource that aims to teach information from all parts of the world through videos (Duffy, 2008). As a result of the literature review, it is seen that YouTube-supported education is widespread in the field of medical education and studies have been carried out in this field. Rössler, Lahner, Schebesta, Chiari and Plöchl (2012) expressed their opinion on the preparation of higher quality and institutional medical learning videos by making video quality reviews of lumbar function and spinal anesthesia concepts taught with videos on YouTube. YouTube has been used as an educational material in other fields besides medical education. Almurashi (2016) stated in an experimental study at Taibah University that YouTube played a leading role in helping students understand the English language. McAlister (2014) recommends using YouTube for occupational therapy instructors seeking innovative ways to improve their courses because of low cost of producing digital videos and uploading to YouTube is low. In the literature, YouTube was used as a course material in the field of Engineering education and Computer Engineering education. For example, Carlisle (2010) uploaded videos of 21 lessons to YouTube in order to prepare students for the Java lesson and applied a questionnaire to the students about how often they watched the videos and how much this activity contributed to their learning. As a result, the students stated that the video materials helped them learn. In the study, it was revealed that the students also performed successfully in their exams thanks to the video materials. It was concluded that the videos on YouTube can not only be a course material, but also a simple introduction or advertising for the university.

Method

The aim of this study is to reach the opinions of the computer engineering students about their YouTube usage profiles and the educational use of the videos published in YouTube. Therefore, the research was designed as a survey within the quantitative research paradigm. Survey research scans the whole or part of the population in order to reach a general judgment (Karasar, 2012). The sample of the study was composed of 100 undergraduate students (72 male 28 female) studying in the Department of Computer Engineering at the Süleyman Demirel University, Isparta, Turkey. A questionnaire was developed to collect the data consisting of participants' demographic features, their use of the Internet and YouTube, and their goals and opinions regarding the use of YouTube for educational purposes. Items were adopted from similar studies in the literature exploring students' view and behaviors towards videos shared on YouTube and purposes of watching YouTube (e.g., Alp & Kaleci, 2018; Lai, 2013). In the questionnaire form, a total of 10 items were asked to collect data about the participants' use of YouTube for academic purposes and the participants rated them using a 5-level Likert-type measure where "strongly disagree=1" and "strongly agree=5".

Results

Regarding demographic characteristics of the participants, 72% of them were male and 28% were female students. The reason why females are less than males may that the expectation of competence in being successful in professions and higher education programs in which men are the majority differs according to gender (Bozgeyikli, 2005). The participants were equally distributed according to their class levels, %25 for freshman, sophomore, junior and senior. The ages of the participants varied between 18 and 33 and the mean age was 21.94 years (SD=2.82).

It was observed that 72% of the participants used a smart phone as the primary device to access the internet. This finding indicates that the participants can access the internet from anywhere at any time. When looking at the daily internet usage of the participants, it differed from 2 hours to 18 hours with an average of 6.40 hours (SD=3.48). As far as their YouTube behaviors were concerned, 72% of the participants mostly used YouTube compared to social media platforms. 84% of them were subscribers to YouTube channels that produce educational content. Only one participant (1%) reported that he/she did not watch educational videos via YouTube. According to the frequency of their visits to YouTube, 57% of them used it much and 17% of them used it very much. It was revealed that 84% of the participants' purpose of visiting YouTube was mostly watching the videos of others for pleasure and entertainment. More than half (67%) also visited YouTube for learning and academic purposes.

Table 1. Participants' Views on Educational Usage of YouTube Videos

Opinion	**Mean**	**SD**
Being able to repeat the subject I do not understand in the lesson with the videos on YouTube as many times as I want helps me to understand.	4.14	.92
I get support from YouTube videos while working for midterm and final exams.	4.13	1.02
Videos on YouTube help me understand the subject.	4.07	.75
I get the opportunity to learn at my own pace with the videos on YouTube.	4.01	.83
I try to understand the subject that I do not understand at school by watching the videos on YouTube.	3.95	.90
I can learn a lesson I have not taken at school by watching YouTube videos to improve myself.	3.92	.91
I think my success level has increased thanks to the videos on YouTube.	3.61	.94
I can learn what I have learned from videos on YouTube by reading a book or articles on a computer screen.	3.42	.98
I find videos on YouTube boring.	2.41	.95
I find learning from YouTube videos unnecessary.	1.59	.92

Not. Scores from 5-point Likert scale ranging from "1=strongly disagree" and "5=strongly agree".

Table 1 demonstrates the opinions of the participants on educational usage of YouTube videos. On average participants agreed with the statements like "Being able to repeat the subject I do not understand in the lesson with the videos on YouTube as many times as I want helps me to understand" (Mean=4.14, SD=.92), "I get support from YouTube videos while working for midterm and final exams" (Mean=4.13, SD=1.02), "Videos on YouTube help me understand the subject" (Mean=4.07, SD=.75), "I get the opportunity to learn at my own pace with the videos on YouTube" (Mean=4.01, SD=.83), "I try to understand the subject that I do not understand at school by watching the videos on YouTube" (Mean=3.95, SD=.90), "I can learn a lesson I have not taken at school by watching YouTube videos to improve myself" (Mean=3.92, SD=.91), "I think my success level has increased thanks to the videos on YouTube" (Mean=3.61, SD=.94), "I can learn what I have learned from videos on YouTube by reading a book or articles on a computer screen" (Mean=3.42, SD=.98) whereas they were undecided about the statement "I find videos on YouTube boring" (Mean=2.41, SD=.95) and they disagreed with the statement "I find learning from YouTube videos unnecessary" (Mean=1.59, SD=.92).

An exploratory factor analysis was performed to explore the factorial structure of the statements in Table 1. The scree plot of eigenvalues suggested a single factor solution. Since it is common in the literature to have a minimum of 0.30 factor loading, one item was removed and the remaining nine items, whose factor loadings differed from .46 to .85, were summed to create a composite variable to represent participants' overall opinion about the usage of YouTube videos for educational purposes (Mean=33.00, SD=4.67).

An independent-samples t-test was conducted to compare participants' opinions across gender (Table 2). There was no significant difference [$t_{(98)}=1.40$, $\eta 2=.01$, $p>.05$] in opinions between males (Mean=33.42, SD=4.74) and females (Mean=31.96, SD=4.41). Similarly, a one-way between-groups analysis of variance (ANOVA) was conducted to explore grade level differences in participants' opinions (Table 3). There was no significant difference [$F(3, 96)=.56$, $p>.05$] in opinions among freshman (Mean=33.04, SD=5.23), sophomore (Mean=33.44, SD=4.63), junior (Mean=32.00, SD=4.56) and senior (Mean=33.56, SD=4.34). Participants' opinions were not significantly correlated with their ages ($r=.07$, $p>.05$) and daily internet use ($r=.11$, $p>.05$).

Table 2. Comparison of Participants' Opinion by Gender

Gender	N	Mean	SD	t	p
Male	72	33.42	4.74	1.40	.16
Female	28	31.96	4.41		

Table 3. Comparison of Participants' Opinion by Grade Level

Grade level	N	Mean	SD	F	p
Freshman	25	33.04	5.23	.56	.63
Sophomore	25	33.44	4.63		
Junior	25	32.00	4.56		
Senior	25	33.56	4.34		

Conclusion

Participating computer engineering students access the internet primarily from smart phones and highly interact with the internet on a daily basis. YouTube is the most used social media among the participants. They subscribe to channels that produce educational content and watch educational videos. They use YouTube mostly for entertainment and academic purposes. The students believe that the videos on the site have educational functions such as repetition, compensation, individual learning opportunities, and preparation for exams. Therefore, sharing the videos that educators will share with their students as an introduction or preliminary preparation on the YouTube website can make it easier for the students to come to the class prepared. Supporting the lessons via YouTube videos can give students the chance to listen to the lesson again and increase their success level. The quality of educational videos to be shared on YouTube will encourage the use of YouTube for academic purposes.

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Investigating Psychological Effects of E-sports Games on Players

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Abstract: E-sports games have recently become a popular internet game especially among young people and are played at a professional and amateur level. The effect of replacing traditional games with such digital games on the development of children and young people is hotly discussed among the parents and educators. This study aims to investigate psychological problems of players arising from playing e-sports games. The research was designed with a survey model. The sample consisted of 100 players that were accessed over the internet. The data were collected using an electronic questionnaire prepared by adapting the computer games addiction scales. The majority of the participants are high school students and their average age is 17.5 years. About half of them have e-sports experience of five years and above. It is seen that the participants have low level addiction problems in the dimensions of "associating e-sport with real life" and "neglecting responsibilities because of e-sport" and medium level addiction problems in the dimensions of "preferring e-sport to other activities" and "can not giving up e-sport". Gender, age and school type have no effect on these dimensions.

Keywords: Electronic games, E-sport, Psychological effects, Addiction, Youngsters

Introduction

As a result of rapid developments in the digital age and related transformative effects, the concept of traditional sports has been changed just like the other activities and the concept of e-sports has entered our lives. E-sports is the abbreviation of electronic sports. Over the last decade, as a new kind of sports, it has become one of the most popular activities, especially in adolescents and emerging adult culture. Since it is still a developing concept, there are a few definitions of e-sports in the literature. For example, Wagner (2006) defines it as a sports activity where people improve their physical and mental skills through information and communication technology (ICT). According to Rosell (2017) it is playing video or computer games in a competitive environment based on the rules. For Newzoo (2018) it includes meeting of players towards a specific goal in a tournament based on mutual competition over the computing networks. Within the framework of these definitions, Büyükbaykal and İli (2020) state that it is a sport emerging from the cooperation of entertainment

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and sports and it is based on mutual competition, played individually or as a team through various electronic devices, including sponsors, organizers and viewers. All these definitions indicate that the concept of e-sports includes ICT, sports and entertainment.

E-sports games are developed as highly interactive virtual environment accessed by digital devices and they allow players to take control of a person or an object and perform functions specific to each game. They are usually played either individually or in teams for an award or title. E-sports games are often organized as national or international amateur or professional tournaments that involve sponsors, organizers and viewers/fans (Akın, 2008). Back in the days video games were only played for recreation and entertainment and the only viewers were friends, siblings and family members but over the years the reach of video games has become widespread with high viewership. Nowadays millions of fans watch e-sports daily and support their favorite teams at stadiums.

Not all computer games can be regarded as e-sports. E-sports games can be divided into several categories such as First-Person Shooter (FPS), Multiplayer Online Battle Arena (MOBA), Massively Multiplayer Online Games (MMOG), Role Playing Games (RPG) and Sport Games (Büyükbaykal & İli, 2020). FPS games (e.g., Call of Duty, Halo, Counter Strike) involve the player taking control of a character holding a handgun or other form of projectile, which is usually the central focus of the game. MOBA games (e.g., League of Legends, Defense of the Ancients) are strategy-based video games in which two teams compete against each other on a predefined battlefield. MMOG (e.g., World of Warcraft) are often played on the same computer server with hundreds or thousands of players. RPG (e.g., Star Wars) involve the player taking control of a character in a fictional virtual setting. Sport games (FIFA, Football Manager) are traditional sports branches adapted to virtual environments.

E-sport games have recently become a popular internet game especially among young people. According to data comes from NewZoo, which is the world's most trusted and quoted source for games market insights and analytics, e-sports audience increased from 395 million viewers in 2018 to 454 million the following year, expecting that by 2022 the audience will exceed 645 million viewers (Pannekeet, 2019). More than half of these are from Asia-Pacific region where e-sports is very popular. Even though e-sports was not so popular in the beginning, in recent years it has turned into a billion-dollar industry. As the number of spectators increased, the revenues of this industry increased as well. According to Newzoo statistics, in 2018 earnings from e-sports amounted to over $865 million, reaching $1.1 billion in 2019 and projected to increase to almost $1.8 billion in 2022 (Pannekeet, 2019).

The potential consequences of playing e-sports on both the development and future of the new generations have been noted and debated by scholars, educators as well as parents. There is a growing public concern and discussion about these games. However, there is no agreement about the effects of e-sports among the experts and their study results. Some show that playing e-sports may result in increases brain stimulation, developing critical thinking skills, quick reactions (increasing hand-eye coordination), having fun, relieving stress, making money, on the other hand, some indicate that high involvement in these games may lead to time management problems, sleep deprivations, weight gain, obesity, physical complaints (e.g., eye straining, backache), increase in aggressive behavior, rash decision-making, and addiction (Can & Tekkurşun Demir, 2020; Saito, Isogai & Takahashi, 2021; Sarper Kahveci, 2020). Of course, it is not possible to make final and certain judgments because there is not enough research on these consequences. A recent bibliometric analysis of previous research studies conducted in the last 15 years indicates that the number of studies conducted on e-sports in the last five years increased and are more than the previous years (Büyükbaykal & İli, 2020). The most research on this subject is from China, United States, South Korea and Germany, where e-sports games are very popular and related sector is developed. This topic and related studies are still in their development stages. There is a need for more studies especially in different cultures and populations in the word to make final assertions.

The effect of replacing traditional games with such digital games on the development of children and young people is hotly discussed among the parents and educators. However, while the studies in the literature focus on addiction and muscle and skeletal problems caused by intense internet usage, they are limited in terms of the psychological and physical effects of e-sport games on the players. Therefore, in this study, it was aimed to investigate the psychological problems of the players arising from playing e-sports games and their relationships with some demographics. In order to fulfill this purpose, the following research questions were formed:

- To what extend are players addicted to e-sports games?
- Do their addiction levels differ across gender and education level?
- Are their addiction levels related to age?

Method

Since this research explores the current state of the potential psychological consequences of e-sports players based on their self-report data from a descriptive point of view, it was designed with survey research model within the quantitative research methods. Survey studies are generally conducted to explore how opinions, attitudes, or characteristics are distributed in the sample, a part or the whole of the target population, rather than how they originate (Buyukozturk, Kilic, Cakmak, Akgun, Karadeniz & Demirel, 2011). They aim to reveal the existing situation on a particular subject, to explain, compare and describe attitudes and behaviors (Karasar, 2012). Within the framework of this research methodology, this study was structured in a quantitative research context that includes data collection within a scale.

The population of this research includes amateur and professional level e-sports gamers living in Turkey. Using a criterion-based convenience sampling, the sample comprised 100 volunteer gamers accessible over the Internet. This sampling method adds speed and practicality to research because the researcher chooses a situation that is close and easy to access (Büyüköztürk et al., 2011).

The data were collected using an electronic questionnaire that was shared with players on the related Internet forums and social media platforms. In the first part of the questionnaire form there were some questions to solicit personal information and gaming profile. During the examination of related literature, no specific scale was found to measure the psychological effects of e-sports games on players. Thus, the Computer Games Addiction Scale (CGAS) by Horzum, Ayas and Çakır Balta (2008) was adapted to e-sports games. The CGAS has a total of 21 5-point Likert-type items (1=completely disagree, 5=completely agree). The items are grouped under four main dimensions: inability to stop e-sports and be bothered when blocked, dreaming of e-sports and associating it with real life, neglecting responsibilities due to e-sports, and preferring e-sports to other activities.

Results

Of the participants, 86% of them were male and 14% were female players. The majority of the participants (84%) are high school students while the remaining slight parts (16%) are university students. The ages of the participants ranged from 15 and 27 and the mean age was 17.54 years (SD=2.72). Regarding e-sports experience, 23% have been playing e-sports games for less than a year, 32% for 1-4 years, and 45% for five years and above. The frequency of weekly e-sports gaming was distributed as follow: 1-10 hours (54%), 11-20 hours (24%), and 21 hours and more (22%).

The participants' item scores in the CGAS were summed up for each dimension to calculate dimension scores. After this, the mean scores and standard deviation of each dimension in the CGAS were calculated and presented in Table 1. The mean score for the "inability to stop e-sports and be bothered when blocked" dimension was 30.38 (SD=6.26) while the actual scores ranged from 9 to 43. The mean score for the "dreaming of e-sports and associating it with real life" dimension was 9.31 (SD=3.26) while the actual scores ranged from 4 to 17. The mean score for the "neglecting responsibilities due to e-sports" dimension was 7.28 (SD=2.57) while the actual scores ranged from 3 to 13. The mean score for the "Preferring e-sports to other activities" dimension was 10.40 (SD=3.18) while the actual scores ranged from 4 to 19.

Table 1. Participants' Addiction Scores

Addiction dimension	Min	Max	Mean	SD
Inability to stop e-sports and be bothered when blocked	9	43	30.38	6.26
Dreaming of e-sports and associating it with real life	4	17	9.31	3.26
Neglecting responsibilities due to e-sports	3	13	7.28	2.57
Preferring e-sports to other activities	4	19	10.40	3.18

Independent-samples t-tests were conducted to compare participants' addiction scores across gender (Table 2). There was no significant difference [$t_{(98)}$=1.42, p>.05] in "inability to stop e-sports and be bothered when blocked" addiction dimension between males (Mean=30.02, SD=6.45) and females (Mean=32.57, SD=4.52). There was no significant difference [$t_{(98)}$=1.21, p>.05] in "dreaming of e-sports and associating it with real life" addiction dimension between males (Mean=9.15, SD=3.21) and females (Mean=10.28, SD=3.50). There was no significant difference [$t_{(98)}$=.79, p>.05] in "neglecting responsibilities due to e-sports" addiction dimension between males (Mean=7.20, SD=2.64) and females (Mean=7.79, SD=2.08). There was no significant difference [$t_{(98)}$=.79, p>.05] in "preferring e-sports to other activities" addiction dimension between males (Mean=10.29, SD=3.23) and females (Mean=11.07, SD=2.78).

Table 2. Comparison of Participants' Addiction Scores by Gender

Addiction dimension	Gender	N	Mean	SD	t	p
Inability to stop e-sports and be bothered when blocked	Male	86	30.02	6.45	1.42	.16
	Female	14	32.57	4.52		
Dreaming of e-sports and associating it with real life	Male	86	9.15	3.21	1.21	.23
	Female	14	10.28	3.50		
Neglecting responsibilities due to e-sports	Male	86	7.20	2.64	.79	.43
	Female	14	7.79	2.08		
Preferring e-sports to other activities	Male	86	10.29	3.23	.85	.40
	Female	14	11.07	2.78		

Independent-samples t-tests were also conducted to compare participants' addiction scores across education level (Table 3). There was no significant difference [$t_{(98)}$=1.45, p>.05] in "inability to stop e-sports and be bothered when blocked" dimension between high school (Mean=30.77, SD=6.04) and university students (Mean=28.31, SD=7.18). There was no significant difference [$t_{(98)}$=.75, p>.05] in "dreaming of e-sports and associating it with real life" dimension between high school (Mean=9.41, SD=3.25) and university students (Mean=8.75, SD=3.38). There was no significant difference [$t_{(98)}$=-.27, p>.05] in "neglecting responsibilities due to e-sports" dimension between high school (Mean=7.25, SD=2.61) and university students (Mean=7.44, SD=2.42). There was no significant difference [$t_{(98)}$=.89, p>.05] in "preferring e-sports to other activities" dimension between high school (Mean=10.52, SD=3.25) and university students (Mean=9.25, SD=2.79).

Table 3. Comparison of Participants' Addiction Scores by Education Level

Addiction dimension	Education	N	Mean	SD	t	p
Inability to stop e-sports and be bothered when blocked	High school	84	30.77	6.04	1.45	.15
	University	16	28.31	7.18		
Dreaming of e-sports and associating it with real life	High school	84	9.41	3.25	.75	.46
	University	16	8.75	3.38		
Neglecting responsibilities due to e-sports	High school	84	7.25	2.61	-.27	.79
	University	16	7.44	2.42		
Preferring e-sports to other activities	High school	84	10.52	3.25	.89	.38
	University	16	9.25	2.79		

When Pearson correlation coefficients were calculated, it was revealed that players' age was not significantly associated with "inability to stop e-sports and be bothered when blocked" (r=-0.18, p>.05), "dreaming of e-sports and associating it with real life" (r=-0.05, p>.05), "neglecting responsibilities due to e-sports" (r=-0.01, p>.05), and "preferring e-sports to other activities" (r=-0.13, p>.05) dimension scores.

Conclusion

Participating e-sports players in this study have low level addiction problems in the dimensions of "associating e-sport with real life" and "neglecting responsibilities because of e-sport" and medium level addiction problems in the dimensions of "preferring e-sport to other activities" and "cannot giving up e-sport". They show some symptoms of both cognitive and behavioral occupation with e-sports and unsuccessful efforts to control e-sports gaming behaviors. Individual item scores of the CGAS suggest that there seems to be a displacement effect of e-sports gaming on participants' other activities (e.g., going out, hanging with friends, sports). Players' addiction problems are not dependent on their gender, age and education level. In order for e-sports players to be less psychologically affected by e-sports games, time arrangements can be made regarding playing e-sports games; since young players may start living in the world of games, it can be emphasized that the games are independent from the real world by ensuring their socialization; it should be ensured that the players focus their attention on their main responsibilities; and e-sports players can be directed to normal sports and by this way supporting their psycho-social and physical development.

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