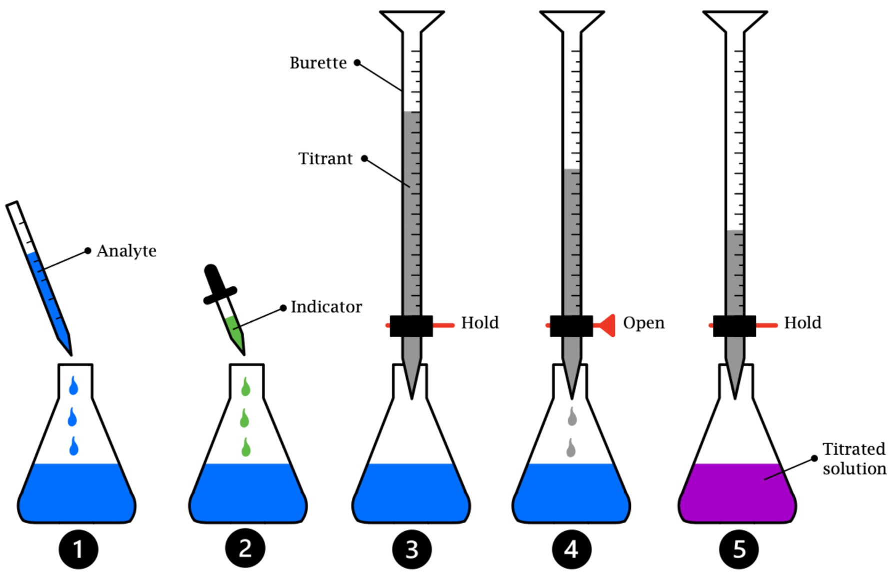
Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Natural Sciences
Department of Materials Science and Engineering

Frode Strømsnes

Development and implementation of new laboratory tasks in general chemistry

Master's thesis in Materials Science and Engineering
Supervisor: Gerhard Henning Olsen
Co-supervisor: Christian Lauritsen
June 2023



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Preface

This master's thesis was submitted to the Department of Materials Science and Engineering at the Norwegian University of Science and Technology (NTNU). The work was conducted from January 23 to June 19, 2023, under the guidance of Gerhard Henning Olsen as the main supervisor and Christian Lauritsen as the co-supervisor. I am sincerely grateful to both of them for their invaluable support and guidance throughout the entire semester. Their availability for weekly meetings and prompt assistance at any time has been greatly appreciated. They provided me with constructive feedback on various aspects, ranging from minor details to more substantial issues. Their expertise in the field fostered meaningful discussions and further motivated my research.

I would also like to extend my gratitude to Elin Harboe Albertsen for generously providing me with laboratory resources, chemicals, and assistance at short notice. Additionally, I would like to thank the others involved in general chemistry for helping me.

Abstract

This study investigates Task 6 – Titration of strong and weak acid in the general chemistry courses TMT4110 and TMT4115 at NTNU. The main goal is to enhance student learning and experience. The investigation involved analyzing the level of cognitive skill using Bloom's taxonomy and interpreting the task as degree of inquiry. Relevant theory was employed, the laboratory task was executed to closely simulate a student's experience, the students performing the experiment were observed, and interviews were conducted with two laboratory groups before and after the laboratory exercise.

The relevant theory implies that a more open laboratory instruction style is not always the most effective method for enhancing the student's learning outcomes and understanding. Interviews with students indicated Task 6 struggled to achieve all the intended learning objectives and the students prioritize time over learning during the experiment. Based on these insights, the recommendations for the laboratory task are to keep the traditional expository instruction style, update the learning objectives and assure that the objectives are clearly communicated in all stages of the laboratory exercise. Furthermore, it is recommended to streamline the task by focusing solely on Part 2, and lastly, develop new preparatory tasks to promote all the higher-order cognitive skills, achieve all the learning objectives and include all the essential acid-base titration concepts.

These recommendations can benefit not only the specific chemistry courses analyzed, but also other chemistry courses that involve laboratory activities, aiming to improve student learning outcomes and understanding.

Sammendrag

Denne studien undersøker Oppgave 6 - Titlering av sterke og svake syrer i de generelle kjemikursene TMT4110 og TMT4115 ved NTNU. Hovedmålet er å forbedre studentenes læring og opplevelse. Undersøkelsen involverte analyse av det kognitive ferdighetsnivået ved hjelp av Bloom's taksonomi og graden av åpenhet gjennom inquiry. Relevant teori var brukt, laboratorieoppgaven ble gjennomført ved å etterligne en studentopplevelse så nært som mulig, studentene som utførte eksperimentet observert, og det ble gjennomført intervjuer med to laboratoriegrupper både før og etter laboratorieøvelsen.

Den relevante teorien antyder at en mer åpen laboratorieundervisningsstil ikke alltid er den mest effektive metoden for å forbedre studentenes læringsresultater og forståelse. Oppgave 6 slet med å oppnå alle de tiltenkte læringsmålene, og studentene prioriterer tid fremfor læring under eksperimentet. Basert på disse innsiktene, anbefales det å beholde den tradisjonelle ekspositoriske undervisningsstilen, oppdatere læringsmålene og sikre klar kommunikasjon av målene i alle faser av laboratorieøvelsen. Videre bør oppgaven fokusere kun på Del 2 og utvikle nye forberedende oppgaver som fremmer alle de høye kognitive ferdighetene, oppnår alle læringsmålene og inkluderer alle de essensielle syre-base titreringskonseptene.

Disse anbefalingene kan være til nytte ikke bare i de spesifikke kjemikursene som ble analysert, men også i andre kjemikurs som inneholder laboratorieaktiviteter med mål om å forbedre studentenes læring og forståelse. Det er viktig å erkjenne at denne studien ble begrenset av en enkelt person, noe som potensielt kan ha påvirket resultatkvaliteten og begrenset perspektiver og synspunkter.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

TMT4110 General Chemistry is a first-year chemistry course offered by the Department of Materials Science and Engineering at NTNU in the spring [1]. The fall equivalent is the course TMT4115 General Chemistry [2]. The general chemistry courses are compulsory for all master's level engineering programs at NTNU. The course aims to provide an introduction to the theoretical and practical aspects of various chemistry subjects through a combination of conventional lectures and compulsory laboratory activities [1, 2]. Throughout the semester, the students go through numerous laboratory exercises from the TMT4115 activities, as can be seen in Figure 1. The tasks in the figure are obtained from the laboratory course compendium and are numbered accordingly to align with the compendium [3]. Additionally, the figure illustrates which tasks from the compendium are included in each General Chemistry course.

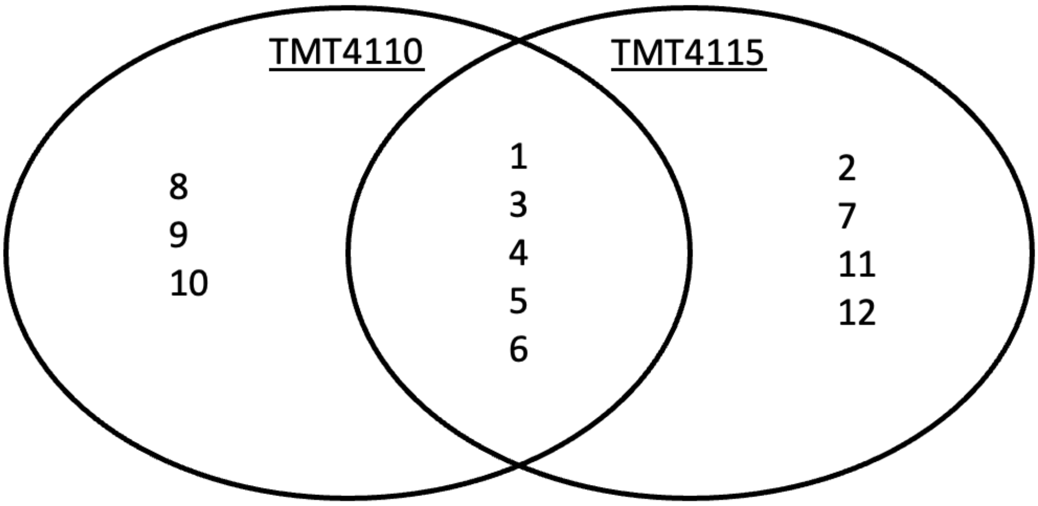


Figure 1: Laboratory tasks in TMT4110 General Chemistry and TMT4115 General Chemistry [4].

Laboratory tasks have a longstanding tradition in the curriculum of general chemistry subjects and are frequently included as part of course design with clear objectives and content. Students generally engage in practical work in the laboratory following a predetermined set of instructions. Subsequently, they write a laboratory report, detailing the practical implementation, methodology, results, and interpretation. This instructional format is also widely adopted in physics courses, but recent studies have shown that a "recipe-based" laboratory approach may not necessarily offer the optimal academic benefit to students [5–7]. Experience among the teaching staff at NTNU in general chemistry indicates that students tend to be more preoccupied with the time taken to complete laboratory tasks and may not fully comprehend the experiments until much later, if at all.

Titrations have been a fundamental and important component of the introductory chemistry curriculum for decades, particularly the acid-base titration which involves the neutralization of acids with bases and vice versa [8, 9]. This aspect of chemistry is traditionally covered in general chemistry textbooks and laboratory manuals [8]. Titration analysis has a wider area of application than, e.g., gravimetry analysis. They are also faster and easier to implement and execute [9]. At the same time, this concept is among the most difficult subject for students to learn [8, 10].

The Acid-base titration is covered by Task 6 – Titration of strong and weak acid in both TMT4110 and TMT4115, as can be seen in Figure 1. Given that titration has been a part of general chemistry courses for so long - have the learning outcomes been kept sufficiently up to date?

1.2 Scope of this project

The aim of this project is to improve Task 6 – Titration of strong and weak acid in both TMT4110 and TMT4115 (Figure 1) in a way that results in greater "ownership" of the exercise by the students, and further enhance student learning outcomes and experience. The aim is to involve the students more in the planning and implementation of the exercise, by analyzing the tasks with respect to the degree of inquiry and cognition, executing the laboratory exercise, observing the students while performing the exercise and interviewing students. By connecting and comparing the feedback and observations to relevant theory, specific ways to improve the exercise and better meet the goals of an ideal laboratory task can be identified.

2 Theory

2.1 Acid-base titration

Acid-base titration is the most prevalent type of titration where an acid and a base are the reactants. The goal of the chemical analysis method is to reach the equivalence point. Either by adding an acid to a base or a base to an acid. The product is a titrated solution where the added acid (H^+ or H_3O^+) with a known concentration (the titrant) is equal to the amounts of base (OH^-) originally in the unknown solution (the analyte), in moles [9, p. 55].

A strong acid titrated with a strong base reacts through Reaction 1:

$$\mathrm{H^+ + OH^- \rightarrow H_2O} \tag{1}$$

But if a weak acid, HA, is titrated with a strong base, they react through Reaction 2 [9, p. 59]:

$$\mathrm{HA + OH^- \rightarrow H_2O + A^-} \tag{2}$$

In order to determine when the titration is complete, an acid-base indicator can used. The indicator changes color at a specific pH value. Consequently, by utilizing this property and selecting an indicator that changes color at the equivalence point of the solution [9, p. 59].

The pH, the acidity in a solution, is calculated by Equation 3,

$$\mathrm{pH} = -\log(c_{\mathrm{H^+}}), \tag{3}$$

where c_{H^+} is the concentration of total acid in the solution [11, p. 101].

By plotting the pH with respect to the relative volume of a strong base, a titration curve is obtained, as can be seen in Figure 2 for both strong and weak acids.

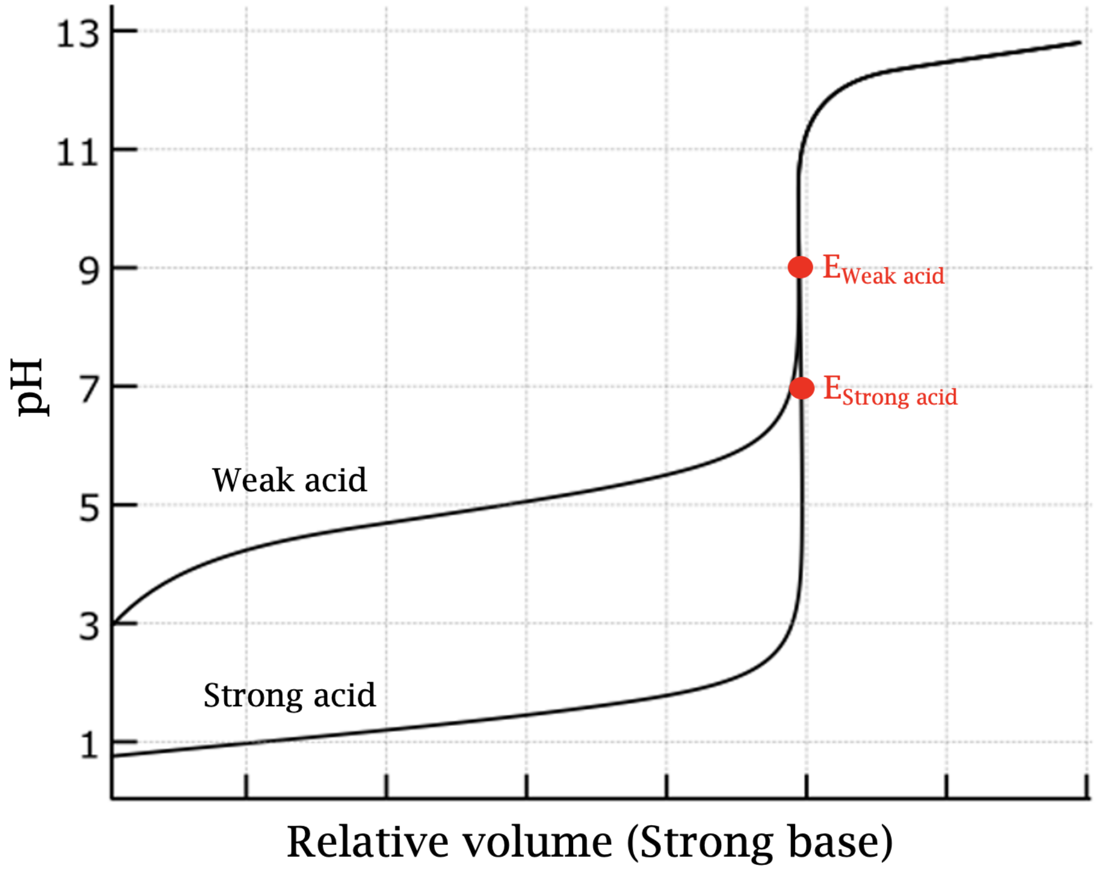


Figure 2: Titration curve of a weak and strong acid, showing pH with respect to relative volume strong base. Modified from [3].

These curves can be used to find the equivalence point. In titration with strong acid and strong base, the equivalence point is at $pH = 7$ (neutral solution). For titration with weak acid and strong base, the equivalence point is at $pH > 7$ (basic solution). Both equivalence points are shown in Figure 2. In contrast, titration with a strong acid and weak base results in an equivalence point at $pH < 7$. However, this case will not be further examined in this study. [11, p. 101].

The strength of an acid or a base is determined by their respective dissociation constants, K_a and K_b. A weaker acid or base is characterized by a lower value of $K_{a,b}$ [11, p. 99]. The dissociation constant for an arbitrary weak acid, HA, is given by:

$$\mathrm{HA}(aq) + \mathrm{H_2O}(l) \rightleftharpoons \mathrm{A^-}(aq) + \mathrm{H_3O^+}(\mathrm{aq}) \tag{4}$$

$$K_a = \frac{[\mathrm{H_3O^+}][\mathrm{A^-}]}{[\mathrm{HA}]}, \quad ([\mathrm{H_3O^+}] = \frac{c_{\mathrm{H^+}}}{c^0_{\mathrm{H^+}}} = c_{\mathrm{H^+}}), \tag{5}$$

where $[H_3O^+]$ is the concentration of H_3O^+, $[A^-]$ the concentration of A^- and [HA] the concentration of HA. For a weak acid, the concentration of H_3O^+-ions (or H^+-ions) are lower, and therefore, a lower K_a-value.

The acid-base titration method can be divided into five simple steps, as illustrated in Figure 3.

1. Fill an Erlenmeyer flask with the analyte. Note the volume.
2. Add an indicator that changes color at the equivalence point, to know when to stop the titration.
3. Fill a burette with the titrant (either acid or base depending on the unknown in stage 1) and hold it over the Erlenmeyer flask. Note the volume.
4. Open the valve carefully and add the titrant slowly into the analyte.
5. Close the valve upon color change. Note the volume difference from stage 3. The flask should now contain the titrated solution.

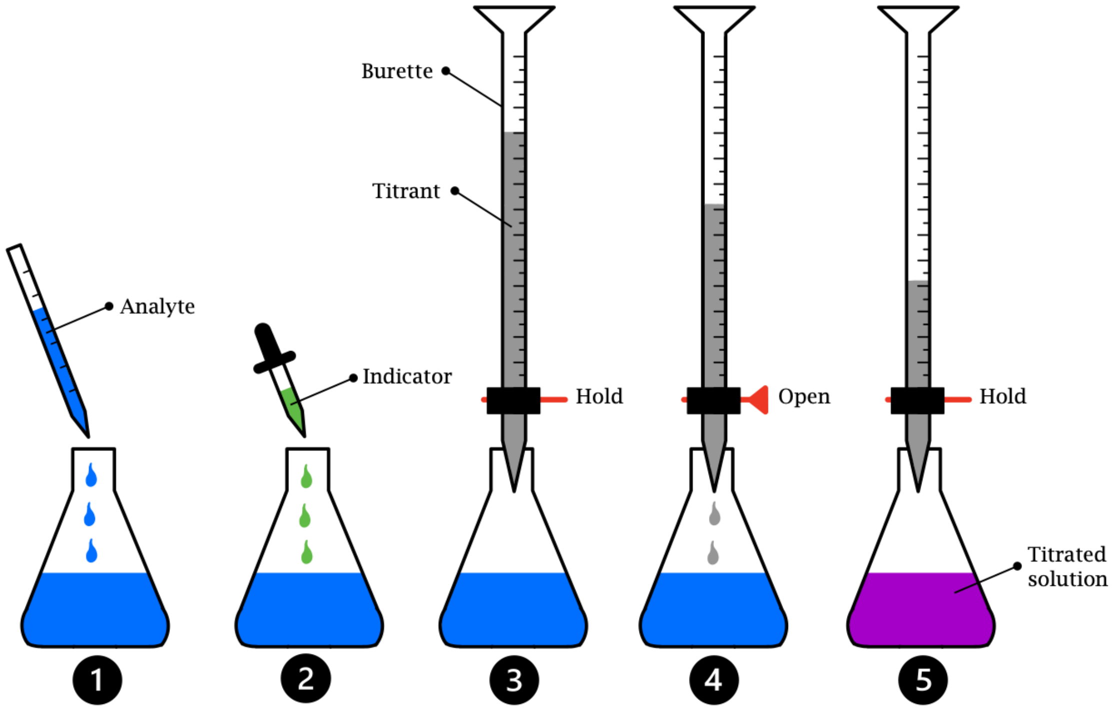


Figure 3: The five steps of acid-base titration illustrated.

Førland's [9] section about titrations and acid-base titrations implies the following concepts important to understand the chemical analysis methods:

- Acid-base reactions
- Titration setup

- Indicator selection
- Acid-base titration curves
- Equivalence point
- Sources of error and error analysis

2.2 Laboratory activity

Laboratory engagement plays an important role in science education, offering students an opportunity to explore the practical aspects of science beyond the theoretical aspects like lectures and calculations. By engaging in laboratory experiments, students act in the role of researchers and develop essential problem-solving skills [12]. The laboratory should aim to involve and enhance, skills relating to learning, practical skills, scientific skills and general skills such as team working and reporting [13]. The laboratory environment opens up for interaction between the students and teachers and is a way to vary the science environment to enhance student learning [12].

The introduction to Førland's [11] laboratory book from 1988 states the following:

"It is important to see both experimental activity and theory in context. With a theoretical background and understanding, you will usually do better experimental work – and the work goes faster. On the other hand, experimental work will promote the learning of theory if you see the connection. By utilizing the connection between theoretical and practical subjects you can achieve a "synergistic effect", the results in both areas will be better than if you see the subjects separately – better with a smaller total work." (Translated from Norwegian)

Meaningful learning can be achieved through laboratory activities when students are actively involved in manipulating materials and equipment to construct their own understanding [14]. However, students often lack sufficient time and opportunity for metacognitive learning during laboratory tasks [12]. Metacognitive learning involves self-monitoring and enhancing the learning process and further understanding [15]. This is in the laboratory typically limited to simple procedures and tasks such as explanation and observation. To promote deeper learning, laboratory activities should encourage students to manipulate ideas, engage in reflection, and foster inquiry through questioning and hypothesis formulation [16]. It is important to recognize that the cognitive processes taking place within students' minds are just as significant as the physical actions they undertake in the laboratory, "minds-on as well as hands-on", as stated by Hofstein et al. [12].

In order to create an optimal learning environment, laboratory personnel should empower students by allowing them to have as much control as possible. However, studies have shown that students often lack a clear understanding of the objectives of laboratory activities and tend to prioritize finding the correct answers or following instructions without deeper reflection [12]. To maximize the benefits derived from laboratory work, it is essential for students to possess a solid foundation of knowledge regarding experimental procedures before entering the laboratory. This necessitates thorough preparation by laboratory personnel, not only to enhance learning outcomes, but also to improve efficiency and the quality of experimental results [9].

The attainment of laboratory objectives is more likely when students possess a clear awareness of what those objectives entail. Hodson, as referenced by Hofstein and Lunetta [12, p. 39], emphasized in 2001 that a breakdown in communication occurs when students' perception of the objectives differs from those set by laboratory personnel. To enhance the achievement of laboratory objectives, it is imperative for personnel to ensure that students comprehend the objectives of the laboratory experiment. These goals, which may vary across different laboratory settings, should be explicitly communicated to students prior to, during and after their engagement in the laboratory [12]. The laboratory instructor has a tendency to focus on presenting their subject through laboratory activity rather than meeting the student's needs. As mentioned earlier, the need for clearly formulated objectives and further formulated to the students is important. This involves, what is to be taught, who is it to be taught to, by what means, and most important, what are the intended learning outputs [13]? Research shows that students gain a deeper understanding when a smaller number of topics are explored in greater detail, as opposed to a larger number of topics with shallower coverage [12]. Johnstone and Wham, as referenced by Reid and Shah [13], stated in 1982 that actual learning in terms of understanding is minimal in a typical laboratory since the laboratory manual generates information overload for the students, as illustrated in Figure 4 below:

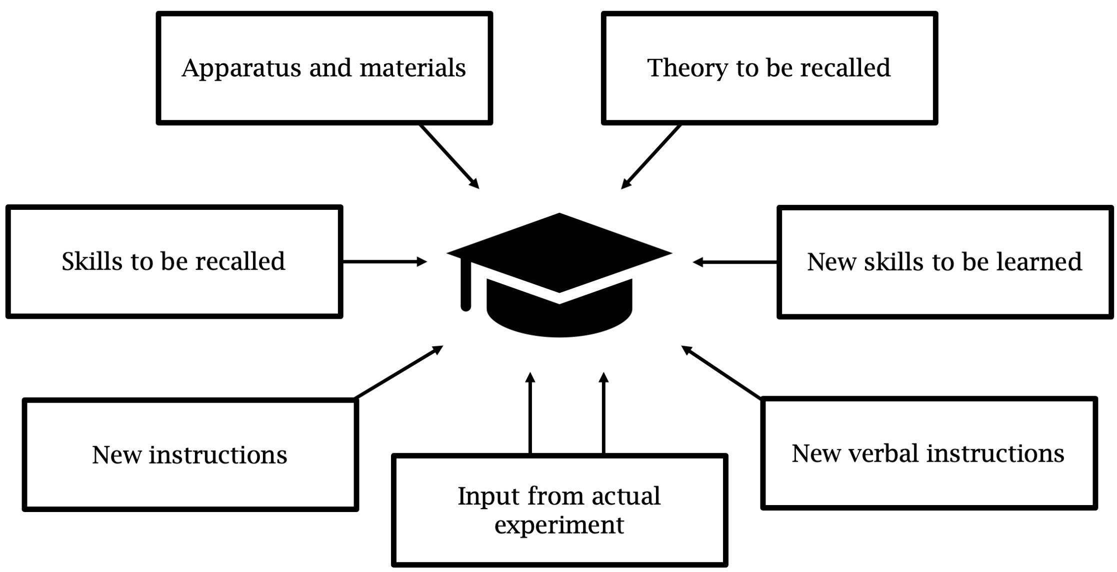


Figure 4: Sources of information for students in the laboratory. Modified from [13].

Consequently, pre-laboratory tasks are introduced to minimize this information overload by generating an understanding before the experiment, as well as reducing the length of the laboratory manual. A pre-laboratory task is an assignment or experience to be completed before the laboratory experiment. Additionally, the exercises can close the gap between what is expected of the students and their perceptions. In other words, they can enhance understanding [13]. The performance of pre-laboratory exercises have been shown to be effective in enhancing understanding and attitude about a laboratory course [17, 18].

As a result, all parts of the laboratory exercise must be seen holistically, as illustrated in Figure 5 below.

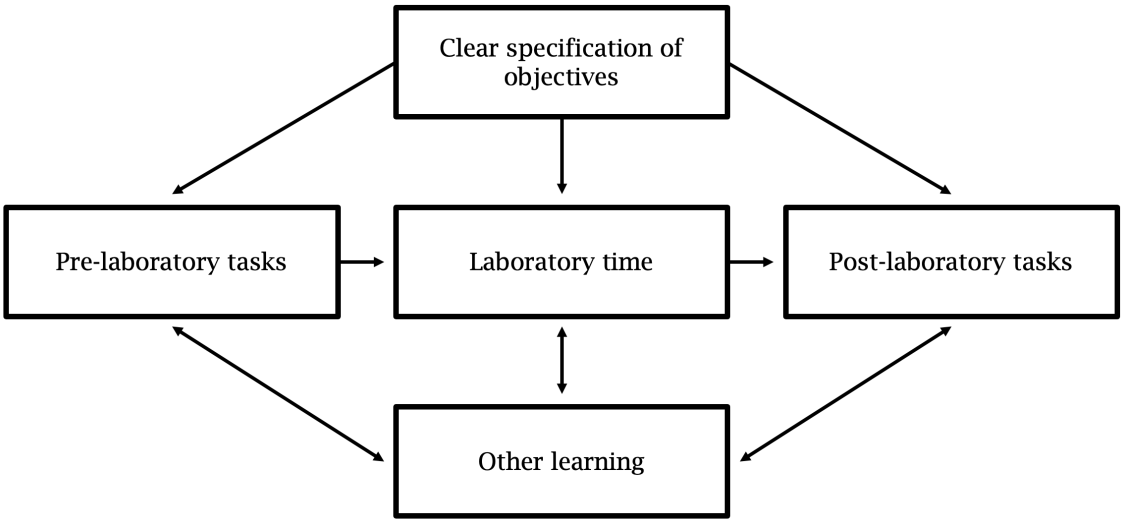


Figure 5: How the focus should be on a laboratory exercise. Modified from [13].

To summarize, Carnduff and Reid [19, p. 31] stated in 2003: "To change the experience, you don't need to change the experiment, just what you do with it."

2.3 Bloom's taxonomy

The categorization of educational activities through taxonomy has been a longstanding practice. Bloom's taxonomy, which is widely used today, was first developed and published in 1956 by Bloom et al. [20]. The taxonomy's original framework comprised six major categories within the cognitive domain: *Knowledge*, *Comprehension*, *Application*, *Analysis*, *Synthesis*, and *Evaluation*.

Bloom's taxonomy was revised in 2001 to update its six major categories. The *Knowledge* category was renamed to *Remember*, while *Comprehension* was changed to *Understand*. The remaining three categories, *Application*, *Analysis*, and *Evaluation*, were renamed to their verb forms to align with how they are typically used in educational objectives: *Apply*, *Analyze*, and *Evaluate*, respectively. Additionally, the *Synthesis* category was renamed to

Create, and its position was swapped with *Evaluate*. Distinct verbs are used to classify each category, as shown below ([21], pp. 214-215).:

1. **Remember** – Retrieving relevant knowledge from long-term memory.
   (a) Recognizing
   (b) Recalling
2. **Understand** – Determining the meaning of instructions messages, including oral, written, and graphic communication.
   (a) Interpreting
   (b) Exemplifying
   (c) Classifying
   (d) Summarizing
   (e) Interfering
   (f) Comparing
   (g) Explaining
3. **Apply** – Carrying out or using a procedure in a given situation.
   (a) Executing
   (b) Implementing
4. **Analyze** – Breaking material into its constituents parts and detecting how the parts relate to one another and to an overall structure or purpose.
   (a) Differentiating
   (b) Organizing
   (c) Attributing
5. **Evaluate** – Making judgments based on criteria and standards.
   (a) Checking
   (b) Critiquing
6. **Create** – Putting elements together to form a novel, coherent whole or make an original product.
   (a) Generating
   (b) Planning
   (c) Producing

The list depicts the cognitive domain as a hierarchy that increases in complexity from level 1 to level 6, with *Remember* being the least complex and *Create* being the most complex. Consequently, *Remember*, *Understand*, and *Apply* are classified as lower-order cognitive skills, as they involve minimal thinking. In contrast, *Analyze*, *Evaluate*, and *Create* represent higher-order cognitive skills [22]. This hierarchy is illustrated in Figure 6 below.

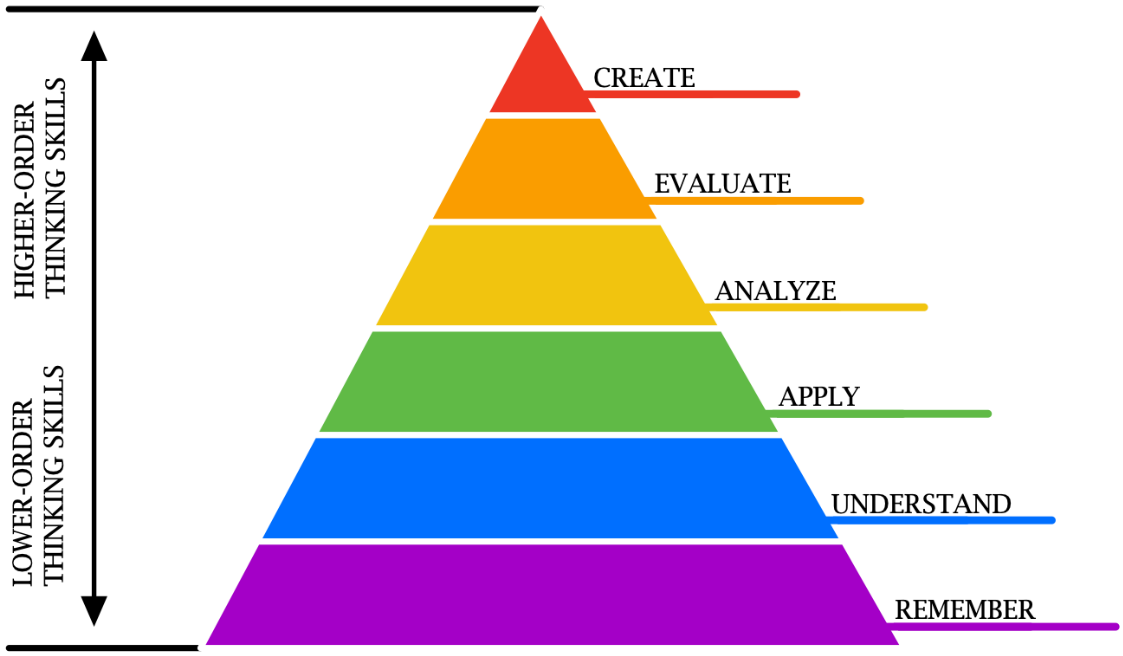


Figure 6: Bloom's hierarchy of the lower-order and higher-order cognitive levels. Modified from [23].

Objectives that only require simple cognitive skills, such as recognition and recall of information, are categorized as lower-order objectives. The higher one progresses in the cognitive hierarchy, the more significant the lower-order cognitive skills become. In order for a student to evaluate and create something new, the student must be able to understand the concept and apply the knowledge in a given situation, and further relate the different parts of the concept to one another. The higher-order cognitive skills are dependent on the lower-order skills. In other words, less complex cognitive skills are more independent [22]. According to Krathwol's [21] 2001 revision of Bloom's taxonomy, the most crucial skills in education are those from *Understand* through *Create*.

Work has been devoted to analyzing educational objectives and elevating them to higher-order categories that require more complex cognitive skills. Furthermore, it is important to compare and contrast the breadth and depth of curricula, exercises, and laboratory instructions [21].

2.4 Style of laboratory instruction

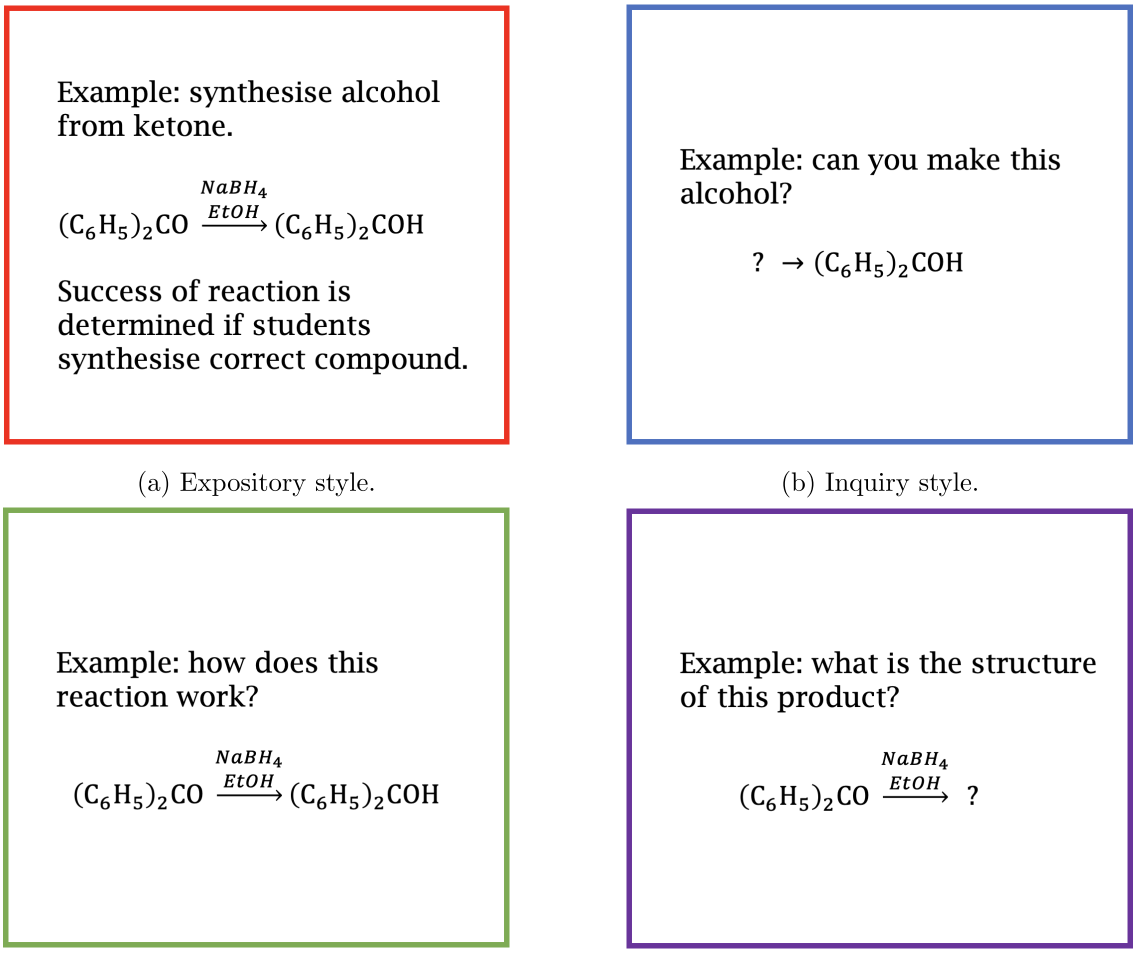
Laboratory instructions are often used to guide students through specific procedures and teach experimental techniques. However, reviews suggest that these instructions often fail to reach their full potential, promoting little learning for students, and focusing more on completing tasks than learning theory [24]. This "recipe-based" style is the easiest to implement, but not the most beneficial. The traditional laboratory activities are designed to facilitate lower-order thinking skills and rote learning [25]. Rote learning, or repetitive learning, involves memorization based on repetition [26]. The repetitive nature of the traditional laboratory, therefore, is a good alternative for learning experimental techniques and equipment. According to Bada and Olusegun [27], rote learning activities do not promote experiential learning (learning through problem-solving) and understanding. Specific procedures promote little thinking and further learning as the students need little knowledge to complete the laboratory experiment [28]. To improve the learning outcome, different laboratory styles can be used, such as expository, inquiry, discovery, and problem-based instruction [25]. These styles can be distinguished by outcome, approach and procedure, as shown in Table 1.

Table 1: An overview of the different laboratory instruction styles. The colors correspond to those in Table 3 later.

Style	**Descriptor**		
	Outcome	**Approach**	**Procedure**
Expository	Predetermined	Deductive	Given
Inquiry	Undetermined	Inductive	Student-generated
Discovery	Predetermined	Inductive	Given
Problem-based	Predetermined	Deductive	Student-generated

A predetermined outcome refers to the expectation that results have already been determined before entering the laboratory, while an undetermined outcome indicates the opposite. The deductive approach involves applying a given principle to understand a larger phenomenon, while the inductive approach involves deriving a general principle from specific observations. Laboratory procedures can be (either) provided in the laboratory manual or generated by students themselves.

Figure 7 below shows how a chemistry task would look in the different laboratory instruction styles.



(a) Expository style. (b) Inquiry style.

(c) Discovery style. (d) Problem-based style.

Figure 7: How a chemistry task would look for each of the four different laboratory instruction styles. Modified from [29].

The expository instruction method follows a cookbook or "recipe-based" approach, where students follow a given manual or the instructions of a task, the teacher or assistant, as exemplified in Figure 7a [30]. This method aims to maximize the number of students conducting the experiment simultaneously while minimizing resources such as time, equipment, and personnel [31]. In contrast, inquiry instruction, or open inquiry, requires students to generate their own procedure and analyze the results, which places more responsibility on them and fosters higher-order cognitive skills [32]. Figure 7b represents this style, where the students would be solely presented with the result, encouraging independent thinking and problem-solving. Guided inquiry, or discovery style, is inductive and requires students to reach a predetermined outcome with the guidance of an instructor. As can be seen in Figure 7c, they are provided with sufficient information to start the investigation. Problem-based instruction, on the other hand, takes a deductive approach, but the procedure is student generated like inquiry instruction and the starting point is usually a problem or a puzzle, as shown in Figure 7d [25, 33].

Both discovery and problem-based instruction methods require a greater level of instructor involvement and student knowledge than the expository approach, as they foster higher-order cognitive skills and require prior knowledge about the subject being investigated [25]. While expository instruction is currently the most widely used method, it has also received the most criticism of the four styles. It has been criticized for failing to facilitate the development of higher-order thinking skills, having little relevance to real-life scenarios, and failing to promote students' interest, enjoyment, and sense of accomplishment when conducting experiments [30, 34]. It is worth noting that different students prefer different types of laboratory instruction styles. More social students tend to prefer working in groups, while more independent students may prefer the organized expository learning approach. Curious students often prefer more open-ended laboratory activities [30]. In summary, the most effective laboratory style varies from student to student and group to group within a classroom.

Goeltz and Cuevas [35] have presented a five-week, discovery-based titration activity as an alternative to the traditional titration laboratory work. More specifically, discovery instruction style with elements of inquiry instruction style for the most interested students. Goeltz and Cuevas' titration approach focuses on total titratable acidity, and the difference between this method and the traditional titration lab is demonstrated in Figure 8.

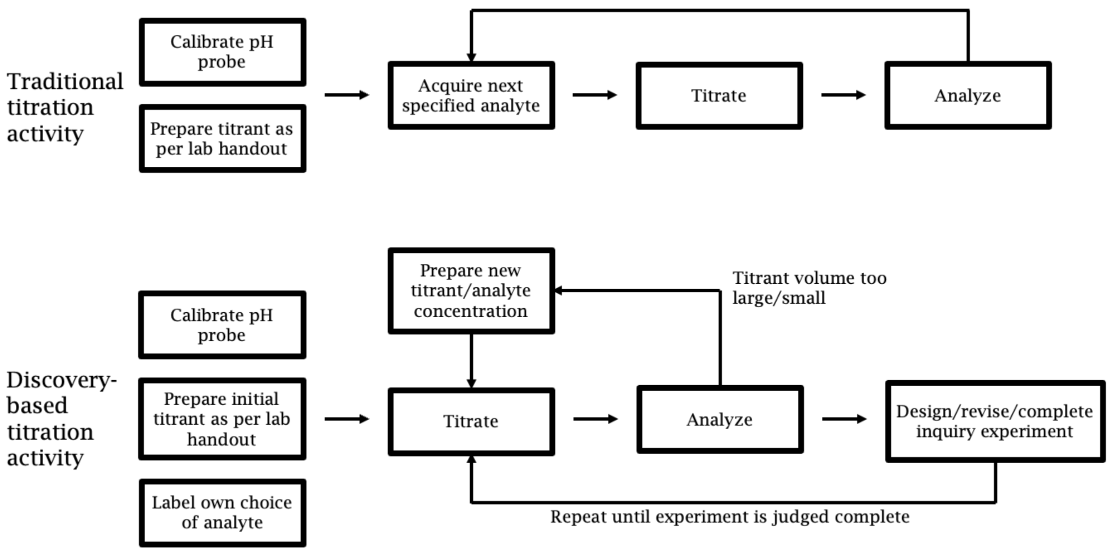


Figure 8: Flowcharts of the traditional titration laboratory activity and the discovery titration laboratory activity. Modified from [35].

The main difference, as can be seen in Figure 8, is that the students choose their own analyte to analyze. Additionally, the students must repeat their titration until their results are satisfactory. After the experiment, the students are required to provide a description of their work that enables the instructor to replicate it.

Around 176 students (around 22 students in eight sections) took a practical exam assessing the outcomes of a titration. As reported by Goeltz and Cuevas, the students participating in the newly designed laboratory activity had a mean score of 6.3 percentage points higher than those taking the traditional approach, consequently evidencing improved learning. Additionally, compared to the traditional "cookbook" laboratories, the responses from students and instructors indicated improved attitudes toward the experiment.

Another approach was utilized by Lin et al. [36], implementing a three-week, discovery-based laboratory experiment investigating a phosphate buffer system. Groups of students first perform the traditional acid-base titration to learn relevant techniques, and further formulate their own procedure and investigate their unknown buffer sample to determine the concentration of all components. According to Lin et al., 89% of the 68 students gave positive feedback to the discovery-based activity. Table 2 shows the percentages of students choosing "strongly agree" or "agree" on statements related to improved skills after the new laboratory approach.

Table 2: Percentage of students choosing "strongly agree" or "agree" to the statements related to improved skills after the investigation of a phosphate buffer system. From the investigation conducted by Lin et al. [36].

Statement from Course Evalution	**Percentage of students choosing "strongly agree" or "agree" [%]**
Because of this course, my skills in using laboratory material and equipment improved.	87.3
Because of this course, my skills in understanding the purpose of laboratory experiments improved.	82.3
Because of this course, my skills in rationalizing laboratory procedures improved.	88.7
Because of this course, my skills in designing experiments improved.	83.9

2.5 Constructivism and constructive alignment

Constructivism has held significant importance in the field of pedagogics for the past 70 years. [37]. The core of constructivism is that knowledge is actively constructed by the mind of the learner, as opposed to being passively transferred from teacher to student [38]. Shiland's five propositions of constructivism suggest modifications to traditional laboratory activities to increase cognitive activity, explore naive theories, challenge existing knowledge, include social components and require application [32]. The five modifications are as follows:

- **Learning requires mental activity;** therefore modify labs to increase the cognitive activity of the learner.
  - Have students identify the relevant variables.
  - Have the students design the procedure or reduce the procedure to the essential parts.
  - Have students design the data table.
  - Use a standard lab design worksheet.
  - Have students suggest sources of error in the lab and modifications to eliminate these sources of error and raise questions about the lab.
- **Naive theories affect learning;** therefore design labs to learn what these are.
  - Move the lab to the beginning of the chapter.
  - Have students make predictions and explain them before the lab.
- **Learning occurs from dissatisfaction with present knowledge;** therefore design labs as problems to challenge their present knowledge.
  - Rewrite the lab as a single problem whose solution is not obvious.
- **Learning has a social component;** therefore design labs to include group and whole class activities.
  - Give the students an opportunity to discuss their predictions, explanations, procedures, and data table before doing the lab, and give them an opportunity to present their results after the lab.
- **Learning requires application;** therefore design labs to require students to find or demonstrate applications.
  - Give students an opportunity to demonstrate applications after the lab.

Naive theories, which are largely subconscious and lack detail, are an important factor in learning [39]. Prior experience, knowledge, and beliefs influence the construction of understanding. The meaningful learning theory by Novak [40] emphasizes the importance of feeling, acting, and thinking during the learning process, particularly during laboratory experiments. Thinking while "doing" is important for the learning process [41].

To enhance learning and ensure that higher-level objectives are addressed, more than one teaching method is used and connected, e.g., lecturing and laboratory activities. On another hand, for improved teaching and further learning, the system of the classroom, i.e. the teacher, the students, the teaching context, the student learning activities and the outcome needs to be addressed as a whole. It is not sufficient to add simple components, e.g., new curriculum, learning methods or learning objectives [42].

Constructive alignment is a principle that utilizes constructivism where the system of *intended learning outcomes*, *learning activities* and *assessment tasks* is aligned [42]. In other words, what the students are intended to learn and further how they are going to express the learning, is stated before the learning starts. Those outcomes are better achieved by designing the teaching to be more student-centered [43].

The *intended learning outcomes* must be described clearly for the system of the classroom explained above. This part of the principle establishes the alignment between the three parts, acting as the link. The four steps to establish constructive alignment, done by John Biggs [43, p. 8]:

1. Describe the *intended learning outcomes* (ILOs) for the unit, using one verb (or at most two) for each outcome. The ILO denotes how the content or topic is to be dealt with and in what context.
2. Create a learning environment using *teaching/learning activities* (TLAs) that require students to engage each verb. In this way, the activity nominated in the ILO is activated.
3. Use *assessment tasks* (ATs) that also contain the verb, thus enabling one with help of predetermined using rubrics to judge how well students' performances meet the criteria.
4. Transform these judgments into final grades.

The assessment tasks should allow the students to present their results to further demonstrate their learning.

Figure 9 shows how a "academic" student's and "nonacademic" student's level of engagement is affected by the teaching method utilized, either passive, e.g., lectures, or more active teaching methods like inquiry or problem-based laboratories.

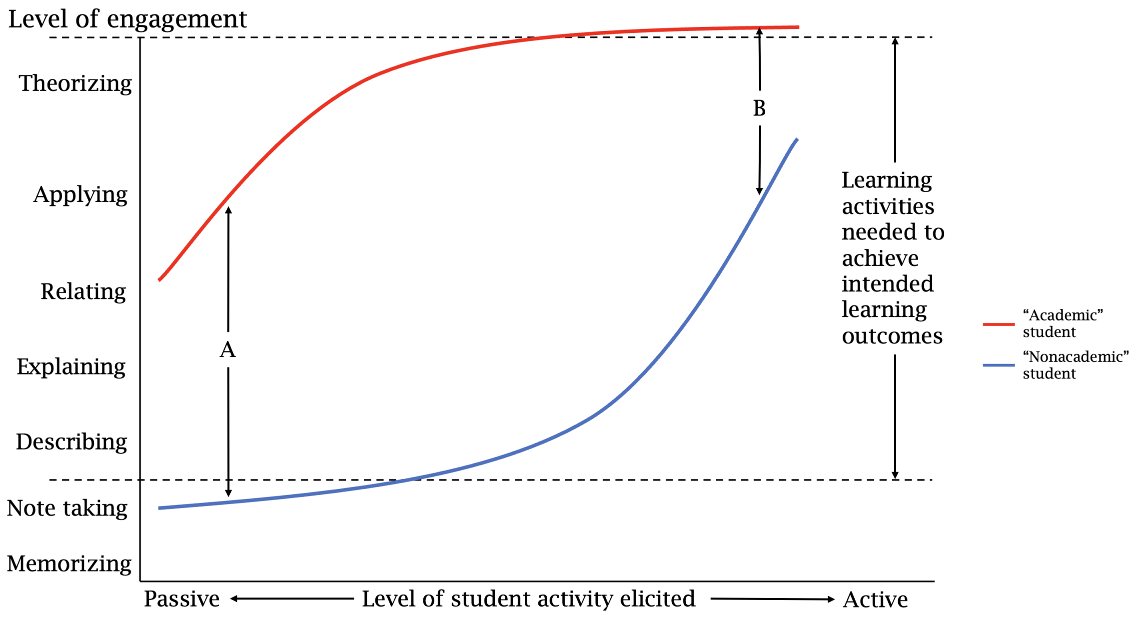


Figure 9: How student orientation and level of engagement vary with the teaching method. Adapted from [44].

An “academic” student is a curious and bright student who strives for success. Conversely, a “nonacademic” student exhibits less motivation and commitment compared to their counterpart [44]. Observed in Figure 9, for more passive teaching methods, the disparity between these types of students, A, is greater than for the difference at active teaching methods, B. During lectures, the “nonacademic” student tends to take notes and memorize the subject matter operating at lower cognitive levels than required. In contrast, the “academic” student demonstrates a higher level of engagement aligned with the desired learning outcomes. A more active teaching approach already fosters higher levels of engagement, resulting in a narrower gap between the two types of students. Consequently, adjusting the pedagogical approach, the learning outcomes from both types of students are more effective [44]. To summarize, Biggs and Tang [44, p. 7] stated in 2011:

Good teaching is getting most students to use the level of cognitive process needed to achieve the intended outcomes that the more academic student use spontaneously.

2.6 Inquiry-based instruction

The term “inquiry” refers to the process of teaching and doing science. In 2000, Colburn [45] defined inquiry-based instruction as open-ended, student-centered, and hands-on activities. While the meaning and implementation of inquiry vary from situation to situation, inquiry is important for promoting understanding and effective learning in science.

Hofstein and Lunetta [12] found that inquiry in a laboratory is essential for the learning process, but it is not sufficient on its own to foster full understanding for the students. To promote effective learning, the teacher needs to guide inquiry to help students construct scientific concepts. Buck et al. [46] developed a rubric to categorize the degree of inquiry in a laboratory exercise based on the level of openness or guidance. The degree of openness used has a significant impact on the pedagogical aspect of the task, with the expository style being more prevalent at lower levels of inquiry.

Table 3 outlines the characteristics that define the degree of inquiry in a laboratory exercise. As can be observed from Table 3, Level 3 – Authentic inquiry is the inquiry laboratory style where every aspect of the laboratory activity is up to the student to manipulate. The first characteristic, *Problem/Question*, pertains to whether the problem to be solved is generated by the students or the laboratory instruction. If the problem is generated by the students, it is classified as a *not provided* case, whereas the opposite holds for problems not generated by the students. *Theory/Background* refers to the preparatory knowledge required to undertake the laboratory experiment. *Procedures/Design* specifies the experimental procedure the students are using in the experiment, either provided or not provided, and up to the students to design. *Result analysis* refers to how experimental results are examined and analyzed, such as through plotting the results or tables. *Result communication* refers to how the results are presented, either in a report (a not provided case) or by filling a template (a provided case). Lastly, *Conclusions* characterizes how the laboratory manual is summarized. The higher level of inquiry, the less structured and student-centered laboratory exercise.

Table 3: How to characterize the level of inquiry in a laboratory task, where the minimum level is Expository instruction style, Level 1: Guided inquiry is Discovery instruction style and Level 2: Open inquiry is Inquiry instruction style in Table 1 [46].

Characteristic	Level 0: Confirmation	Level 0.5: Structured inquiry	Level 1: Guided inquiry	Level 2: Open inquiry	Level 3: Authentic inquiry
Problem/Question	Provided	Provided	Provided	Provided	Not provided
Theory/Background	Provided	Provided	Provided	Provided	Not provided
Procedure/Design	Provided	Provided	Provided	Not provided	Not provided
Result analysis	Provided	Provided	Not provided	Not provided	Not provided
Results communication	Provided	Not provided	Not provided	Not provided	Not provided
Conclusions	Provided	Not provided	Not provided	Not provided	Not provided

The color relationship depicted in Table 1 and 3 demonstrates the connection between laboratory instruction style and the level of inquiry, indicating the extent of openness associated with each approach.

Descriptions of laboratory activities with the different levels of inquiry from Table 3 are given.

- **Level 0 – Confirmation:** At this level of inquiry in a laboratory activity, all characteristics are provided for the students, and the interpretations are obvious by reading and following the laboratory manual. Students are only required to observe, experience and/or learn the unfamiliar phenomenon or laboratory technique without engaging in any problem-solving or critical-thinking activities.

- **Level 0.5 – Structured inquiry:** At this level of inquiry, the students are required to explore and identify new relationships and draw conclusions to a provided problem in the laboratory activity. The laboratory manual still provides guidance for the procedure and result analysis.
- **Level 1 – Guided inquiry:** At this level of inquiry, students are responsible for designing the methods of result analysis, result communication, and drawing conclusions, while the laboratory manual provides the problem and procedure of the laboratory task.
- **Level 2 – Open inquiry:** At this level of inquiry, only the problem to be investigated and the necessary background information are provided to the students, but they are not given any guidance on the procedure, result analysis, result communication, or conclusions.
- **Level 3 – Authentic inquiry:** At this level of inquiry, nothing is provided and it is up to the students to design the entire experiment.

2.7 Thematic analysis

Thematic analysis has been a widely used analysis method in sports and exercise research, as well as in psychology since it was first introduced in the 1970s Holton [47, 48]. Victoria Clarke and Virginia Braun are highly regarded scholars in the field of qualitative analysis, and especially thematic analysis. *Using thematic analysis in psychology* by Clarke and Braun [48] is one of the most cited academic papers of the recent decade. Thematic analysis is according to Braun and Clarke [49] a, "method for identifying, analyzing, organizing, describing, and reporting themes found within a data set". A data set can be an interview or observations. The two experts stated additionally that thematic analysis represents a more accessible form of analysis compared to other qualitative approaches, as it does not require the same level of detailed theoretical and technological knowledge. Therefore, it can be particularly suitable for researchers in the early stages of their careers [49]. It is a way for researchers within different fields to communicate with each other while performing different research methods [50].

Thematic analysis is widely used since a wide variety of topics can be addressed. This method of analysis on open-ended responses, e.g., interviews, provides greater depth into teaching and learning compared to quantitative methods. However, to secure good results it is important to take special care while performing thematic analysis [51]. Like all analysis methods, the analysis should tell the full story of the data and not be arranged to support a specific theory [52]. Regardless of the analytical method employed, the credibility of data analysis is strengthened when multiple researchers analyze the same data [53]. And gives a more detailed analysis result because of collaboration and reflection [48].

Thematic analysis is a flexible approach, but this can lead to inconsistencies in theme naming when analyzing data [54]. Additionally, the use of a simple thematic analysis may not be as rigorous as other methods, as it does not allow for statements about language use [49]. Therefore, while thematic analysis has its advantages, these limitations should be considered when performing the method for data analysis.

There is insufficient literature on how to rigorously conduct and apply this qualitative research method. In response, Nowell et al. [55] addressed this gap in 2017. The study presented valuable insights and recommendations to enhance the rigor of thematic analysis, as can be seen below.

- **Phase 1** – Familiarizing yourself with your data

  This stage of the analysis process entails repeated readings and immersion in the data to identify patterns and meanings. These patterns and meanings become increasingly apparent as the researchers become more familiar with the data [49]. Braun and Clarke [49] recommend at least one thorough reading of the data set to become familiar with its contents and develop ideas about what may be interesting to explore. This phase includes:

  – Prolong engagement with data.
  – Triangulate different data collection modes.
  – Document theoretical and reflective thoughts.
  – Document thoughts about potential codes/themes.
  – Store raw data in well-organized archives.
  – Keep records of all data field notes, transcripts and reflexive journals.

- **Phase 2** – Generating initial codes

  The coding phase of thematic analysis involves identifying important sections of the data set and assigning them names that are indexed and related to a theme. Once the important sections are identified, they are labeled and categorized according to the themes they represent. This phase includes:

  – Peer debriefing.
  – Research triangulation (use of multiple research methods or data sources).
  – Reflexive journaling.
  – Use of a coding framework.
  – Audit trail of code generation.

  - Documentation of all team meetings and peer debriefing.

- **Phase 3** – Searching for themes

  After all the data have been identified and coded, they are organized into relevant themes. It is crucial to distinguish between a deductive and inductive approach during this phase, as it informs how the themes are conceptualized and developed [49]. A theme represents a shared meaning in the data and should not be confused with a domain summary, which is a shared topic rather than a shared meaning [48]. Castleberry and Nolen [52] defined themes as patterns. This phase includes:

  - Research triangulation.
  - Diagramming to make sense of theme connections.
  - Keep detailed notes about the development and hierarchies of concepts and themes.

- **Phase 4** – Reviewing themes

  The reviewing of the themes phase starts when all the themes have been constructed. In this phase, all the codes in the themes are validated to see if they form a pattern and if the theme reflects a meaning. After this phase, the researcher should have a good idea of the different themes and should be able to show how they were devised [49]. This phase includes:

  - Research triangulation.
  - Themes and subthemes vetted by team members.
  - Test for referential adequacy by returning to raw data.

- **Phase 5** – Defining and naming themes

  In accordance with Braun and Clarke's [48] methodology, a theme is commonly labeled using a one-word identifier for a particular domain, or a phrase such as "Type of" or "Drawback of". It is possible for some data to belong to multiple themes, resulting in some overlap [56], nevertheless, the chosen label should provide readers with an immediate comprehension of the theme [49]. This phase includes:

  - Research triangulation.
  - Peer debriefing.
  - Team consensus in themes.
  - Documentation of team meetings regarding themes.
  - Documentation of theme naming.

- **Phase 6** – Producing the report

  The last phase starts when the researcher has fully established all the themes and is ready to conclude the thematic analysis. According to Nowell et al. [55], this phase should provide the reader with a “concise, coherent, logical, repetitive and interesting account of the data within and across the themes”. This phase includes:

  - Member checking.
  - Peer debriefing.
  - Describing the process of coding and analysis in sufficient detail.
  - Thick descriptions of context.
  - Description of the audit trail.
  - Report on reasons for theoretical, methodological and analytical choices throughout the entire study.

The thematic analysis can be divided into five steps: compilation, disassembly, reassembly, interpretation and conclusion [52]. Compilation of data in Phase 1, disassembly of data in Phase 2 before further reassembling the data into codes in Phase 3, interpretation in Phases 4 and 5 to generate and naming themes, and lastly, conclusion in Phase 6.

3 Procedure

First, Task 6 – Titration of strong and weak acid – TMT4110 was selected due to its importance in the chemical curriculum of numerous courses at NTNU (as can be seen in Figure 1) and other universities. Consequently, improving the learning outcomes of this task has the potential to positively impact laboratory courses beyond TMT4110. Notably, Task 6 has remained relatively unchanged in terms of pedagogical enhancements, highlighting a clear opportunity for improvements.

In order to gain a comprehensive understanding of Task 6, the laboratory exercise was analyzed using Bloom's taxonomy to evaluate cognitive levels and inquiry to assess openness. The laboratory task was executed as close to a student as possible in the same laboratory, before observations of students executing the task in the presence of a laboratory assistant. Additionally, semi-structured interviews were conducted with two laboratory groups both before and after completing the task, and the interviews were further analyzed thematically. The findings from this study can inform strategies for improving the effectiveness of learning outcomes for Task 6.

3.1 Execution of Task 6

To get access to the laboratory, the laboratory coordinator for TMT4110 was first contacted. As all the relevant information about Task 6 was provided by the course responsible and laboratory coordinator when conducting the analysis in the specialization project prior to the master thesis, a general understanding of the task was already obtained [4].

The first part involved reading through the learning objectives and all the relevant background theory provided by the laboratory manual, starting with the titration section. Throughout this part of the execution, the learning objectives were kept in mind, since they were intended outcomes to be achieved. As a result, the learning objectives satisfied or not satisfied became apparent. Subsequently, all the preparatory questions were answered and tables were written in a laboratory journal for notes. These tasks can be seen at the end of Appendix C. Further work was done to prepare for the laboratory, i.e. watching a fifteen-minute-long video informing about important EHS-problems regarding the laboratory exercise (careful pouring of 0.1 M NaOH and utilizing a funnel when transferring it into the burette), as well as summarizing the experiment into simple steps with important information and drawings in the same laboratory journal as the tables, as shown in Figures 10 and 11.

In order to mimic a student's experience as closely as possible when performing the experiment, the task was performed slowly and precisely to adjust for a higher level of knowledge than an average student performing the exercise. This approach also allowed for any potential time constraints to be identified.

During the experiment, the laboratory manual was consulted to ensure all the necessary experimental equipment was obtained and the experimental setup was correct. The laboratory experiment was performed in line with the laboratory manual, Part 1 followed by Part 2.

In Part 1, three samples of 0.8 g KHFt salts were poured into three different 300 mL Erlenmeyer flasks and mixed with 50 mL boiled water. Subsequently, one was filled with three drops of methyl red, another one with three drops of phenol red and the last with three drops of phenolphthalein. As illustrated in Figure 10.

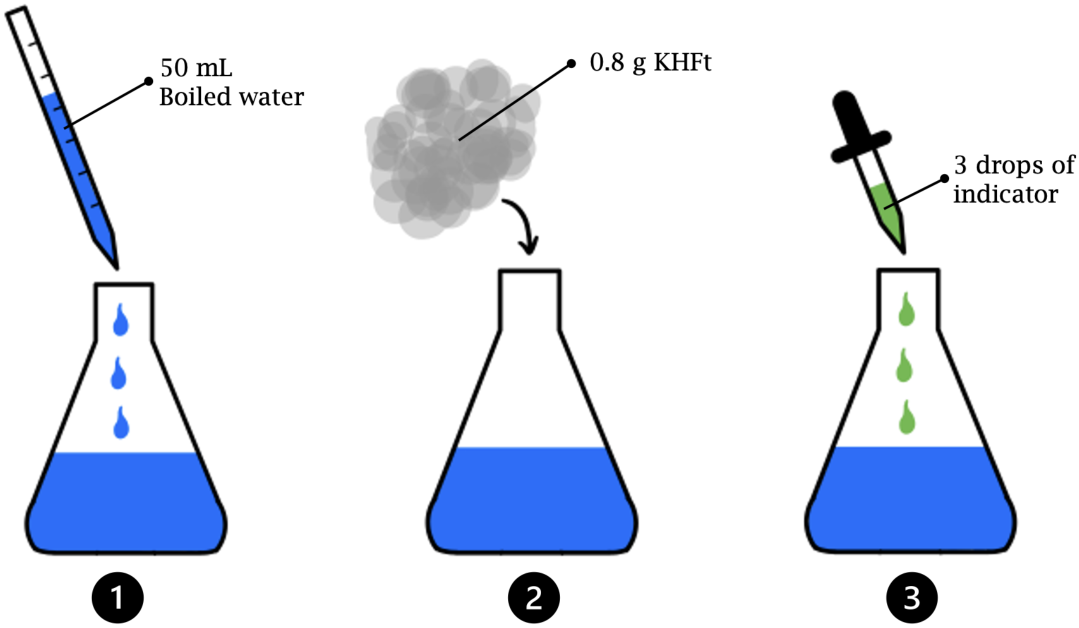


Figure 10: How to prepare the analyte for Part 1.

Subsequently, each one is titrated with NaOH as illustrated in Figure 11. The initial, final and resulting volume changes from the titration were recorded in the tables in the journal from the preparatory work and further used to calculate the molarity of the different acids, as outlined in the manual for both parts of the task. After three titrations for each acid, the average molarity and further the percent deviation were calculated.

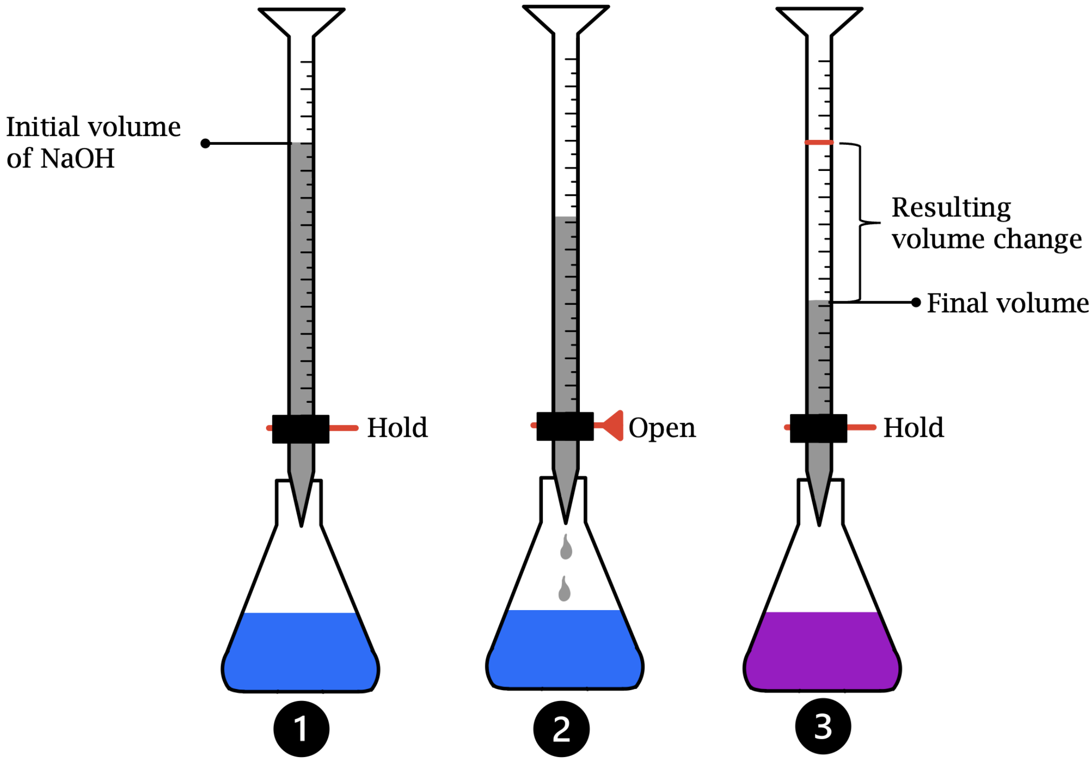


Figure 11: Illustration of titration for Part 1.

Part 2 of the experiment was performed in the same way as Part 1, but the analyte was first an unknown weak acid and afterward an unknown strong acid, both titrated with the titrant NaOH from Part 1.

After completing the laboratory experiment, the calculated values from both parts were compared to the solution given by the coordinator, similar to the students being checked by the laboratory assistant.

3.2 Observation of Task 6

Initially, the laboratory coordinator was contacted to gather information about the scheduling of various laboratory experiments, specifically focusing on when Task 6 was planned to be conducted by the students. Subsequently, the laboratory assistant assigned to the specific laboratory was contacted to observe the students while they performed Task 6.

To ensure a comprehensive understanding of the laboratory experience, it was necessary to access the laboratory prior to the student's arrival. This allowed for an assessment of how quickly different laboratory groups began watching the fifteen-minute preparatory video and whether they viewed the instructional laboratory video at all. During the subsequent laboratory walkthrough conducted by the laboratory assistant, particular attention was given to determining the student's level of engagement during the step-by-step demonstration.

As the students commenced the laboratory experiment, the focus shifted towards evaluating the significance of the laboratory manual for each laboratory group and its correlation with the quality of their preparatory work, as assessed by the laboratory assistant. The focus was on observing whether the well-prepared groups relied less on the manual compared to those with less preparation. By documenting the quality of each group's preparatory work, it became easier to comprehend variations in the initial phase, the progress during the experiment, and the quality of the experimental results between the groups.

During the laboratory assignment, the color of the titrated solution was documented for each laboratory group, providing an indication of the accuracy of their performed titration. These observations were then linked to earlier stages of the experiment. A representation of the notetaking process can be found in Table 4 below.

Table 4: An example of the notetaking during the observation of Task 6.

	Group 1:	**Group 2:**	**Group 3:**	**...**
Preparatory work quality	Good	Below expected	Excellent	
Laboratory manual early use	Frequently	Extensive use	Little use	
Intensity of titrated solution	Overall good intensity, but some with high	Some solutions with high intensity	Good intensity	
Quality of experimental results	Sufficient	Not satisfactory	Excellent	

The laboratory assistant secured that all information, important observations and, e.g., questions from the students were collected.

After the laboratory experiment, the table illustrated as Table 4 was used to more easily remember, compare and draw connections from the observations.

3.3 Interview of two laboratory groups

Following the completion of Task 6 and the observation of students, the initial phase of interview planning involved determining the interview format and establishing the primary objectives. These objectives involve the key objectives that the interviews aimed to address, but are not questioned directly. They help to form the interview questions.

To enable students to respond to the predetermined interview questions while also encouraging the emergence of new ideas, a semi-structured interview format was chosen. Additionally, due to the involvement of a single interviewer, this format was deemed suitable.

Through a comprehensive review of the notes derived from the execution and observation of Task 6, specifically by analyzing the variations among laboratory groups in Table 4 from the observation and considering the defined learning objectives of the laboratory task, a clearer picture emerged. This process facilitated the identification of crucial areas to be explored through questioning, enabling a deeper understanding during the interviews. For example, the intensity of the titrated solution increased throughout the laboratory experiment, and the laboratory manual got less and less utilized. These observations gave rise to a question regarding the time constraints during the experiment and the significance of utilizing the manual. The reduced utilization of the manual might indicate titration control, yet the heightened color intensity of the titrated solution indicated the contrary. Consequently, such points facilitated the formulation of the primary objectives and, subsequently, the development of the interview questions. Figure 12 below illustrates the procedure.

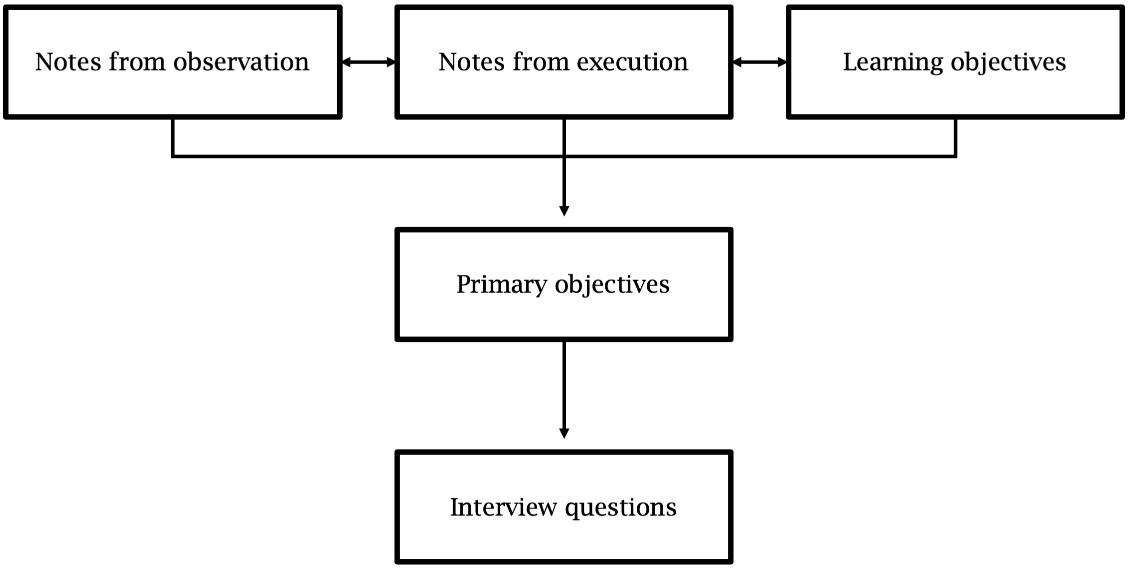


Figure 12: The procedure to construct the interview questions.

Before the interview took place, two students from two different laboratory groups were contacted in order to arrange the interviews, i.e. before and after Task 6. Since the laboratory coordinator provided the time schedule of Task 6 in advance, the organization of the interviews was facilitated.

3.4 Thematic analysis of the interviews

Prior to performing the thematic analysis and after the interviews, the interview texts were transcribed in OneNote, as presented in Appendix A, and subsequently transferred to Excel for further processing, as depicted in Appendix B. Excel was chosen as it provided a user-friendly platform for highlighting text in different colors, incorporating comments, and making modifications given the time-consuming nature of this analysis method. Additionally, it facilitated the differentiation of the various interviews through the utilization of separate sheets for greater management.

3.4.1 Phase 1 – Familiarizing yourself with your data

The interview data were read through slowly at least four times to secure knowledge of the text. The prior transcription into OneNote increased the knowledge about the interview text. Already some patterns and comments arose. The patterns in an interview or specific answer, and comments for a specific answer were noted in Word before transferring the interview data to Excel. Importantly highlighting which interview and answer the patterns or comments belong to. As can be seen in Appendix B, the left column is for comments, the middle column is for answers for each question and the right column is for patterns for each interview, split into independent sheets named "Interview before laboratory of Group 1", "Interview after laboratory of Group 2" etc. Consequently, it was easier to see patterns within an interview and the interviews altogether.

3.4.2 Phase 2 – Generating initial codes

The patterns within an interview from Phase 1 were colored in the middle column and coded after the subject within the pattern in the right column, as seen in Appendix B. The resulting code is colored the same as the pattern. As an illustration, from Appendix A.1.1, the answer, "They think the preparatory work is something they have to do, rather than something they want to do", is a pattern and is therefore colored and further coded after the subject, "Attitude". This code is colored the same as the pattern in the text, as can be seen in Figure 18 in Appendix B.1.1. This process is done throughout the entirety of the interview in Excel. It is important to state that in this phase, the colors of the codes are for relating each pattern with the specific code, in addition to having an overview.

3.4.3 Phase 3 – Searching for themes

After all the interview text was coded and colored, a new sheet was made in Excel with all the codes and their given colors. The new sheet gives an overview of the codes and furthermore, more easily compare them. By comparing the codes and the patterns in the text, the codes with shared meaning were assembled, as can be seen in the right table in Table 5.

Table 5: The codes in the new sheet both before (left) and after assembly (right).

Codes (before assembly):	**Codes (after assembly):**
More chemistry = repetitive	More chemistry = repetitive
Little chemistry = educational	Little chemistry = educational
Lecture and lab	Like chemistry
Like chemistry	Attitude
Video and prelaboratory work	Dislike chemistry
Video -and lecture alignment	Long lab
Illustrative video	Like the lab
Attitude	Time
Preparatory works' goal	Less chemistry = educational
Learning objective	Lecture and lab
Dislike chemistry	Video and prelaboratory work
Lab assistant	Video -and lecture alignment
Preparatory work	Illustrative video
Video	Lab assistant
Long lab	Prelaboratory work
Less chemistry = educational	Video
Liked the lab	The manual
The students assumed learning objectives	Prelaboratory works' goal
The manual	Learning objective
Time	The students assumed learning objectives
Post-laboratory work	Post-laboratory work

For example, the codes "Learning objective" and "The students assumed learning objectives" in the left table in Table 5 share the same meaning, and therefore, in the same theme in the right table in Table 5.

3.4.4 Phase 4 – Reviewing themes

The codes that share the same meaning in Table 5 to the right were equally colored to represent a theme, which formed the left column as can be seen in Figure 22 in Appendix B.3. By going through the newly colored codes, it was easier to check if they shared the same meaning or if one of the codes belonged to another theme, and then change the color of the code. This secured that the codes formed a pattern and a theme reflected a meaning.

3.4.5 Phase 5 – Defining and naming themes

The last phase involved naming the themes constructed in Phase 5, providing the reader with an immediate understanding of the theme. The code Excel sheet made this process easier as the codes related to each other were connected. Initially, the red theme was named "Time", but finally renamed "Influence on motivation". Additionally, the green theme was renamed "Expectations and purposes" from "Purposes". This was done to give a better understanding of the theme, in addition to, the initial names being codes.

4 Results

4.1 Analysis of Task 6 – Titration of strong and weak acid – TMT4110

This specific portion of the results presented here was conducted during the project work prior to the master thesis. For a detailed description of the analysis methodology, see the project work by Strømsnes [4].

The results of the analysis of the laboratory tasks in TMT4110 and TMT4115 are given in Table 6. This information, reveals areas that require updating and provides insights into how the preparatory tasks should be customized to foster higher-order cognitive skills. As can be seen from Table 6, Task 6 – Titration of a strong and weak acid is one of twelve laboratory exercises in TMT4110 and TMT4115. The task is a part of both as described earlier and as can be seen in Figure 1.

Table 6: Analysis of laboratory tasks in TMT4110 and TMT4115 in terms of cognitive skill and level of inquiry [4].

Task	Lower order cognitive skill	Analyze	Evaluate	Create	Inquiry level
1	✓✓	-	-	-	0.5
2	✓✓	✓✓	-	-	0.5
3	✓✓	-	-	-	0.5
4	✓✓	-	✓	-	0.5
5	✓✓	✓	-	-	0.5
6	✓✓	-	-	-	0.5
7	✓✓	✓	-	-	0.5
8	✓✓	-	-	-	0.5
9	✓✓	✓	-	-	0.5
10	✓✓	✓	-	-	0.5
11	✓✓	✓	-	-	0.5
12	✓✓	✓	-	-	0.5

The problem to be investigated, relevant theory, procedure and result analysis are provided, and this task is therefore graded at the level of 0.5 of inquiry based on Table 3. As a result, the laboratory style is more toward expository style. Furthermore, the task includes the lower-order cognitive skills, *Remember*, *Understand* and *Apply*. The preparatory work involves simple questions, they foster no higher-order thinking. There is no reflection on the calculations and drawings, only recall questions with no further process questions.

As part of the preparatory part, the students are expected to perform calculations, provide responses to simple questions, and interpret a given diagram. The experimental part involves the tabulation of experimental results within the designated tables given by the instructional manual. This laboratory task does not foster higher-order cognitive skills, but the preparatory part fosters lower-order cognitive skills as the questions involve recalling, tabulating and solving.

4.2 Execution of Task 6 – Titration of strong and weak acid – TMT4110

The goal of the laboratory exercise is to determine the concentration of unknown acids with high accuracy through several titrations.

The relevant theory, equipment to be used, pre-laboratory tasks and full execution of the laboratory experiment are given in Appendix A.

The laboratory experiment is divided into two parts. In Part 1 is a NaOH-solution standardized before its concentration is determined by titration against a solution of $KHC_8H_4O_4$ with known concentration. In Part 2, the NaOH-solution from Part 1 is used for titration of two unknown acids, one strong and one weak acid, in order to determine their concentrations.

Before entering the laboratory (as can be seen in the appendix) five mandatory questions (for students) related to the experiment need to be answered, i.e., calculations, drawings and text answers. The pre-laboratory work also requires drawing five tables in the laboratory journal. The preparatory questions were useful for obtaining an overview of the laboratory assignment, as well as for feeling in control while doing the experiment.

The preparatory work gave a more overview of the laboratory activity and the experimental procedure, than the learning objectives of the laboratory activity. The tables in the preparatory work helped with organizing and managing the experimental results and did not introduce any thinking skills.

Before beginning the experiment, the students must watch a fifteen-minute video that outlines potential EHS-problems associated with the laboratory activity. This includes specific guidance on handling the chemicals and equipment involved, such as the careful pouring of 0.1 M NaOH and utilizing a funnel when transferring it into the burette. The video also summarizes the relevant theory and experimental procedure, as well as provides some helpful hints for achieving more accurate results. In this case, this was done after the experiment, but the relevant EHS-problems were provided by the laboratory responsible in advance.

Full laboratory execution is provided, and combined with the video, it was easy to have control while doing the laboratory experiment.

As can be seen in the laboratory manual in the appendix, the experiment will provide knowledge and training in:

- Acid-base reactions – ✓
- Titration – ✓✓
- Dissociation constant for weak and strong acid – **X**
- Determine the pH in a solution with the help of indicators – ✓
- Work precisely in the laboratory – ✓✓

X *indicates that the objective is not achieved, ✓ indicates that the objective is achieved to a small extent, and ✓✓ indicates that the objective is achieved. Based on the laboratory manual and experience from the execution of the laboratory.*

The laboratory exercise provided no understanding of the dissociation constant for weak and strong acid and some understanding of acid-base reactions through the numerous titrations in the exercise. But on the other hand, this gave sufficient training in titration, determining the pH in a solution with the help of indicators and working precisely in the laboratory. It is worth mentioning that even though the students perform various and numerous titrations in this laboratory task, they may not be aware of the importance of precise work in this specific task as the video states that the students need to be effective as this is a long exercise. A misunderstanding may occur if the students are not aware of the learning objectives while performing the experiment – the more precise work, the more effective work and further learning.

It is worth mentioning that the student's perception of the learning objectives may be different as their knowledge about the subject is lesser than in this case.

4.3 Observation of of Task 6 – Titration of strong and weak acid – TMT4110

In order to get a greater understanding of how the students execute the laboratory exercise, one of the laboratories was observed. The following observations were made.

Firstly, there are three parallels for each laboratory exercise. According to the laboratory assistant in the parallel observed, all the different parallels differ with respect to:

- How strict the checking of preparatory work is.
- EHS-walkthrough or not.
- How detailed the laboratory walkthrough is.

- If the video is before or after the laboratory.
- How much deviation in the experimental results is tolerated. In one parallel, students with too much deviation must redo the experiment.

In accordance with the procedure outlined in Task 6, all students must view a fifteen-minute video before the laboratory exercise, which is introduced by the laboratory assistant at 2:15 pm. Students view the video independently upon arrival at 2:00 pm and not as a group. Consequently, students who arrive late may miss portions of the video or not view it at all, as the video must be watched prior to the introduction. In this case, the students who arrived late consequently missed important information regarding the laboratory task. As a result, these groups had a slower start, particularly those who were not adequately prepared. Conversely, groups that had dedicated more time to preparation had a more efficient start and produced more accurate results. In some cases, less-prepared groups asked more simple questions that could be answered by reading the theoretical section of the laboratory manual. According to the laboratory assistant, groups who spend more time on preparation generally finish more quickly and produce superior experimental results. This was particularly evident in this laboratory exercise, as less-prepared groups had a more pronounced color change in their titrated solution than better-prepared groups during the initial phase of the experiment, indicating that they added excessive titrant to the unknown solution. In most instances, it is advisable to perform an inaccurate initial titration, as it establishes the approximate equivalence point prior to conducting a meticulous titration. It is worth noting that the color intensity increased as the number of titrations increased, suggesting that students may have become unmotivated by the numerous titrations in the task. Similarly, groups that spent less time preparing for the laboratory exercise relayed more heavily on the laboratory manual. Despite needing help, some groups spent more time figuring it out independently rather than asking the laboratory assistant, and in some cases end up with poor deviation in their experimental results.

To increase student motivation, the laboratory assistant introduced a competition where the group with the smallest deviation in their experimental results was awarded a prize.

In order to reduce time and queue in the weighing room, half of the observed parallel started with Part 1 and the other with Part 2 of the laboratory experiment.

A fault was discovered in the video, which erroneously stated that the chemical used in the experiment should be poured into a specific container when finishing the experiment. In fact, the correct procedure was to pour the chemical into the sink with running water. As a result, all groups spent extra time asking about the specific container and finished the experiment later than necessary.

4.4 Thematic analysis of interview of two laboratory groups

The primary objectives for both the interview before and after the experiment are given below.

- Before the laboratory experiment:
  - Are the students aware of the learning objectives?
  - Do they learn something from the current type of preparatory tasks?
- After the laboratory experiment:
  - Do they have the same perception of the learning objective as before?
  - Have they learned something from the experiment?
  - What do the students want to do to improve the experiment part, or Task 6 in general?

4.4.1 Influence on motivation

During the interviews, it became evident that students from both groups expressed a sense of the laboratory assignment being time-consuming, irrespective of their level of experience with chemistry lab tasks. Student 1 from Group 1, who possessed more experience, found the task repetitive, while Student 2, who had less experience, considered it educational. However, both students agreed on the assignment was lengthy, "... as a result, the final phase of the assignment exhibited a relatively higher degree of carelessness and inaccuracy compared to the initial phase. Ultimately, the focus shifted towards a race against time rather than maintaining a thorough understanding of the process." The perception of time greatly affected the motivation of Student 3, who lacked any prior chemistry experience. Student 3 observed that the focus of Group 2 and the other students seemed to be more on time management rather than on achieving accurate experimental results.

The preparatory video alerted the students about the lengthy duration of the laboratory experiment. Consequently, both Student 1 and Student 2 aimed for precision in their execution, to minimize errors and avoid the need for redoing the experiment. However, the repetitive nature of the task resulted in a noticeable decrease in accuracy during the last part of the experiment for Group 1.

In light of this, Student 3 expressed a preference for transforming the two-part experiment into a single-part experiment, with the intention of reducing the time factor associated with the task, "... this would mean that the students performing the experiment do not get so hung up on time, but rather concentrate more on accuracy."

On the other hand, Student 1 expressed appreciation for the utilization of multiple indicators in the task, as opposed to relying on a single indicator. Similarly, Student 3 also found the color change aspect of the experiment appealing, as it provided a visual representation of the ongoing chemical reactions.

4.4.2 Constructive alignment

Both students in Group 1 express a positive attitude towards the general chemistry course, stating that it is well-structured in terms of both lecture content and laboratory activities. Student 3 specifically appreciates the laboratory experiments as they provide a valuable opportunity to observe the practical application of theoretical concepts discussed in lectures, offering an alternative and effective approach to learning the subject matter.

Student 1 expressed the opinion that the preparatory work, when combined with the pre-laboratory video demonstrating the laboratory procedures, felt excessive. In contrast, Student 3 believes that the video serves the purpose of emphasizing the EHS-issues associated with the laboratory exercise.

Both Group 1 and Student 3 emphasized the importance of the laboratory manual throughout the experiment. In the first part of the laboratory exercise, the group heavily relied on the manual to minimize the possibility of errors. However, as they progressed to the later stages, the manual was used less frequently due to the repetitive nature of the task and their growing familiarity with the titration technique.

Student 3 valued the active laboratory assistant, "...so that they can ask questions, which in turn promotes learning. This helped the student to understand what happens in the laboratory, but also for the learning of the various topics."

4.4.3 Expectations and purposes

Prior to the laboratory experiment, neither Group 1 nor Student 3 had a clear understanding of the learning objectives, except for Student 3 assuming the learning objective of titration as an experimental technique. However, after the experiment, both Group 1 and Student 3 concluded that titration as an experimental technique indeed served as a learning objective. In addition, both Student 1 and Student 3 identified the learning objective of familiarizing themselves with the experimental apparatus. Furthermore, Student 3 expressed the view that the learning objectives were not effectively communicated before, during or after the experiment.

Regarding Task 6, Student 3 finds the preparatory work satisfactory in terms of understanding the procedural aspects of the experiment, but feels that it falls short in explaining the meaning of the laboratory assignment, "... the preparatory tasks is good enough to understand what is to be done during the experiment, more than the meaning of the laboratory exercise."

5 Discussion

5.1 The learning objectives

As observed from the interviews, the learning objectives are not clear for the student in any of the stages of the laboratory activity. This is not in line with the theory of the focus of a laboratory exercise, as can be seen in Figure 5. Clear specification of the objectives must be made in all stages, in the pre-laboratory tasks, laboratory time and in the post-laboratory tasks. As a result, Task 6 misses out on learning outcomes and is less effective than its potential. Furthermore, it misses out on the first step to establishing constructive alignment, done by Biggs [42]. As can be seen from the interviews of Group 1 in "Expectations and purposes" in the thematic analysis, only the learning objective, "Titration" is in line with the student's perception of these goals. But this is only one of the five objectives. Student 3 was not aware of the educational objectives either before, during or after the experiment, but on the other hand, assumed titration as a learning outcome in the interview after the laboratory. Additionally, during the observation in one of the laboratory parallels, the laboratory assistant did not communicate the learning objectives to the students, and therefore, the students' perceptions of these aims are not in line with what is expected of them if they do not read the learning objectives themselves. The interviews indicate that the students do not read the educational objectives since they are not aware of them both before and after performing Task 6. Given that there is no post-laboratory work for Task 6, Figure 5 signifies that the objectives need to be communicated to the students both before and during the experiment in all the laboratory parallels. In other words, through the pre-laboratory tasks and during the experiment by the laboratory assistant and the pre-laboratory video. Student 3 valued the active laboratory assistant, indicating that they are available during the experiment. Consequently, enhance the effectiveness with respect to student learning outcomes and understanding during and after Task 6 through the theory of constructive alignment. Addressing the learning objectives clearly to the students is in line with constructivism for higher-order cognitive thinking and improved learning.

The execution of Task 6 shows only two learning objectives fully achieved, i.e. "Titration" and "Work precisely in the laboratory". On the other hand, the learning objective, "Dissociation constant for weak and strong acid" is not achieved. The last two objectives, "Acid-base reactions" and "Determine the pH in a solution with the help of indicators", are achieved to a small extent. Since the laboratory activity fosters no understanding of the dissociation constant, the learning objective must either be removed or the laboratory changed in order to incorporate the constant. Laboratory task 4, "Acids and bases", is based on the dissociation constant and is a part of the learning objectives. Task 4, as can be seen from Figure 1, is also part of both TMT4110 and TMT4115. As a result, there is no need for the dissociation constant to be a part of this task since Task 4 mainly focuses on this subject and the students therefore already have learned this. Furthermore, according to Førland, the dissociation constant is not one of the most important aspects of acid-base titration to obtain an understanding of the subject. Consequently, the constant does not need to be part of Task 6. The removal opens up for the other two objectives achieved to a small extent to be fully achieved. The first suggestion is, therefore, the following change in Task's 6 learning objectives:

1. Acid-base reactions
2. Titration
3. ~~Dissociation constant for weak and strong acid~~
4. Determine the pH in a solution with the help of indicators
5. Work precisely in the laboratory

The other four objectives are important for learning acid-base titration, Objective 1 in order to understand which reaction happening during titration and what the product in the titrated solution is. Objective 2 is both practically and theoretically significant as this is the main subject of Task 6, and is, therefore, crucial to ensure achieved to the full extent. Objective 4, on the other hand, is important since by utilizing indicators, the students can understand when titration is ended and reactions happening by visual color-change. As a result, Objective 4 is more the practical aspect of Objective 1 if combined. Lastly, Objective 5 is essential in order to ensure that the experimental results are satisfactory. They are all already a part of Task 6 by being minimum achieved to a small extent.

Observed from the other important aspect implied by Førland, acid-base reaction and indicator selection, as well as titration curves are a part of the list of elements. The titration curve is essential to understand acid-base titration. By introducing this as a learning objective instead of the dissociation constant, the students are more likely to learn and understand the titration technique. The titration curves are not transferable to or important in other subjects in the laboratory course, and therefore, are a part of Objective 2 and not an independent learning objective. Likewise, the aspect, "Sources of error and error analysis", is a part of Objective 5. This factor in working precisely in the laboratory is important since reducing all the sources of error and analyzing eventual errors is essential for a laboratory experiment according to the Shiland-step [32], "Learning requires mental activity".

The lack of fully achieved learning objectives is additionally due to the task fostering lower-order cognitive skills, as observed in Table 6. The preparatory part involves recalling, tabulating and solving, and there is no higher-order thinking involved. To improve this changes in the preparatory tasks are necessary since this is the main factor that affects the cognition of Task 6, as can be seen from the reasoning of Table 6.

It has to be stated that "Work precisely in the laboratory" is a practical learning objective, and therefore, will not be affected by changes on the other. Objective 1 and 3 is according to Førland important factors for learning acid-base titration, and for that reason, fully achieving these goals will not adversely impact Objective 2.

5.2 The laboratory instruction style

The discovery-based laboratory experiments implemented by Goeltz and Cuevas [35] and Lin et al. [36], show an increase in learning with respect to titration compared to the traditional expository laboratory instruction style. This is in line with Novak's [41] modifications of constructivism, by letting the students design the procedure, "learning requires mental activity". Additionally, giving the opportunity to demonstrate application after the laboratory in line with "learning requires application". It also fosters higher-order cognitive skills in Bloom's taxonomy [20, 21] up to *Create* since the students have to create their own procedure, and therefore, increased learning and understanding. As said earlier in the laboratory instruction style section, the most effective approach varies from student to student and group to group within a classroom. The laboratory is a more active teaching method, and therefore, as can be seen in Figure 9, the difference between the "academic" -and "nonacademic" students becomes less, and further within laboratory groups. But on the other hand, the difference is still present and a laboratory activity is not always the most effective in all cases. The discovery-based instruction style tends to be beneficial for more social students, while the expository instruction style is beneficial for more independent students. Hence, a more open laboratory activity may not be the most effective approach in all cases. This becomes prevalent through the interviews. A more experienced Student 1 considers Task 6 to be repetitive, as opposed to the less experienced Student 2 and the least experienced Student 3 who considers Task 6 to be educational. Accordingly, the discovery-based approach would have suited Student 1 more than Student 2 and Student 3. The less experienced students, on the other hand, benefit from the traditional expository style in order to learn the techniques and equipment.

According to the laboratory responsible for TMT4110, the main focus is for the students to learn specific experimental techniques, while also the theoretical aspects of the experiments, "the student must learn to walk before they learn to bicycle". The importance of the laboratory environment and content goes hand in hand with the objectives of the exercise. If the sole purpose of adopting a laboratory style is for students to familiarize themselves with specific equipment and experimental techniques, a more open approach may not be essential. In such cases, a laboratory instruction style with a lower level of inquiry, like the conventional expository style, could suffice. The traditional expository approach is based on rote learning and the repetitive nature of the instruction style fits Task 6 to learn titration as an experimental technique, in addition to the experimental equipment. Conversely, the aim of Task 6 is also to facilitate an understanding of the theoretical aspects, and therefore, a more open style may be preferable. The reason for utilizing a more open-ended laboratory style is to make the student learning outcome more effective. While studies indicate its benefits for the learning process during laboratory experiments, it is important to consider that open methods can be more time-consuming and resource-intensive compared to conventional expository styles. When faced with constraints such as the need for exercise reproducibility, limited personnel, or limited space, it may be more practical to consider the traditional expository laboratory instruction style. Considering that the students have different experiences in chemistry, as exemplified with Students 1, 2 and 3, the task must at least be beneficial for the least experienced students. By removal of Objective 3, Task 6, therefore, provides training and understanding in all the learning objectives at different levels. Thus, a change in the laboratory instruction style is not necessary, but rather a modification in the pre-laboratory tasks and the steps provided by Shiland [32] for a greater student learning outcome. Therefore, the inquiry level in Table 6 will remain 0.5. This, however, reduces the pressure on the laboratory assistants since there is only one per laboratory parallel. As said earlier, for improved learning outcomes it is important that the students are aware of the learning objectives in all stages of the laboratory assignment. But on the other hand, this will also improve the effectiveness of Task 6 by making the laboratory instruction style more effective. The reproducibility is also an important element since Task 6 is a part of both TMT4110 in the spring and TMT4115 in the fall.

A laboratory assignment not incorporating a high level of inquiry does not imply its inadequacy, rather, it may necessitate a simpler approach. Clearly defined goals for conducting the laboratory experiment help focus the exercise and ensure alignment with the desired outcomes. For instance, if the objective is to impart knowledge about a specific scientific concept, the design of the exercise can enable students to observe and investigate that concept, benefiting from a higher level of inquiry, as indicated in Table 3. Alternatively, if the goal is to teach students how to use particular equipment or follow specific laboratory procedures, the exercise can provide opportunities for skill practice, without requiring a more complex laboratory style or elevated levels of inquiry. As Carnduff and Reid [19] stated, you don't need to change the experiment to change the experience, just what you do with it.

5.3 The structure and content

As stated in the observation part, to reduce time and queueing in the weighing room, half of the laboratory groups were assigned to start with Part 1 of the experiment, while the other half started with Part 2. This indicates limited space in the laboratory, and consequently, the chronological and pedagogical reason for performing Part 1 before Part 2 and their correlation did not come through for the groups with less preparation. It is evident from the interviews that time is a big factor in motivation during the experiment, resulting in inaccuracy and a higher degree of carelessness in the last part for Group 1. According to Student 3, the main focus while performing the titration seemed to be more on time management rather than accurate experimental results. Additionally, the repetitive nature of the task resulted in inaccuracy for Group 1. The students, as mentioned in Section 2.2, often lack sufficient time for metacognitive learning during the traditional laboratory activities, supporting the results from the thematic analysis. The preparatory video also alerted the student about the long duration and Task 6 is, therefore, not constructed in line with the third step suggested by Shiland [32], "Learning occurs from dissatisfaction with present knowledge".

The competition introduced during the observation seemed to increase the students' motivation. The utilization of multiple indicators and the color change in Task 6 gave an increase in motivation for both the more experienced Student 1 and little experienced Student 3.

To promote deeper learning in Task 6, the students interviewed implied that reducing time and repetitiveness were crucial factors, as can be observed in Section 4.4.1. In this regard, Student 3 expressed a preference for transforming Task 6 from a two-part experiment into a single-part experiment. The student aspired that the time factor would be reduced and the accuracy of the experiment be more in focus while performing the experiment. In addition, Shiland's step number three, "Learning occurs from dissatisfaction with present knowledge" states, "Rewrite the lab as a single problem whose solution is not obvious". Task 6 is a two-part experiment, where Part 1 is standardization and Part 2 is titration of a weak and a strong acid. Taking the suggestion from Student 3 and modifications by Shiland, and the time and repetitiveness aspects into consideration, transforming Task 6 into a single-part experiment effectively addresses these issues. As can be seen from the learning objectives earlier, standardization is not part of the objectives for the laboratory assignment. Additionally, as observed from the preparatory tasks for Task 6 in Appendix C, four out of the five exercises are related to Part 1. In other words, the gap between the student's perception of learning outcomes and what is expected is increased, and further, learning outcomes and the effectiveness of the laboratory task decreased. By introducing standardization as a learning objective the gap can reduce, but it does not solve the four issues stated. By removing Part 1 from Task 6, the students get more time to manipulate both ideas and equipment for metacognitive learning, "hands-on as well as minds-on" and "thinking while doing". It removes the weighing room issues mentioned earlier since there is no need for precise weighing in Part 2, and additionally, the issue in the correlation between the two parts is solved. Moreover, since the students are provided with the 0.1 M NaOH for standardization, the students are still provided with the same strong base. But on the other hand, the laboratory personnel have to do the standardization before the laboratory experiment, putting more pressure on them. Yet, this is not a long procedure. Task 6 without Part 1 is, therefore, in line with Shiland's modifications and Student's 3 suggestion as a single-problem laboratory. Additionally, the laboratory task is in line with the learning objectives, and further, steps 1 and 2 of the four to establish constructive alignment done by Biggs [42]. Therefore, the suggestion is the following change in Task 6 structure and content:

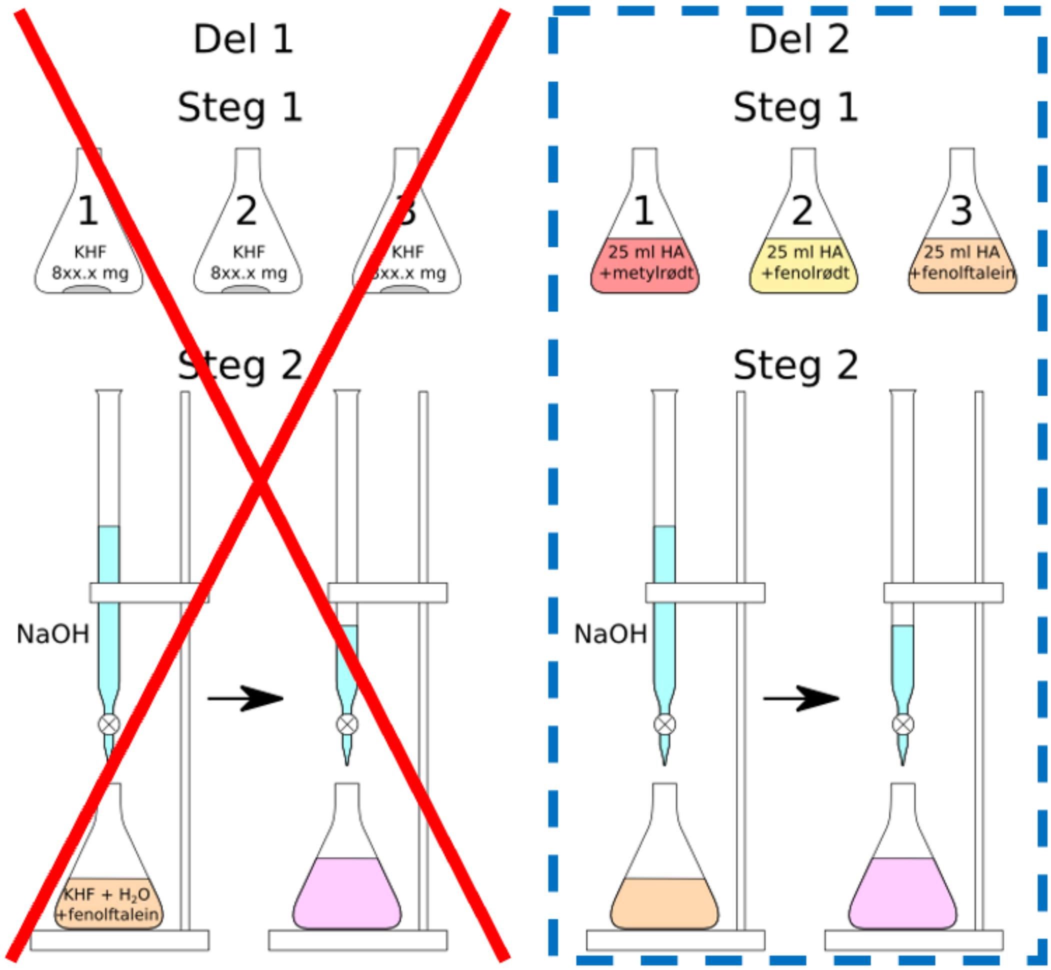


Figure 13: The change suggested with respect to structure and content. Modified from [3].

The modification in structure and content illustrated in Figure 13, still provides the students with enough training in acid-base titration as an experimental technique since it involves titration of both a weak and a strong acid. The expository instruction style is the approach for the part and is, therefore, in line with the suggestion provided in the previous section.

It is important to let the students demonstrate their experimental results after the experiment, to judge how well the laboratory groups perform compared to the solution. Hence, establishing the third step in constructive alignment.

5.4 The preparatory tasks

As said in the Theory section, the preparatory tasks are introduced to minimize the information overload by generating an understanding before the experiment, as illustrated in Figure 4, reducing the length of the laboratory manual. The interviews of the students and observation of the experiment emphasized the importance of the laboratory manual in the initial phase of the experiment. During the observation, the less prepared laboratory groups relayed more heavily on the manual and finished later and obtained worse experimental results. But as stated above, the preparatory tasks are not in line with the learning objectives, and therefore, not motivating the students to be as prepared as possible for Task 6. Moreover, as indicated by Student 3, the preparatory work primarily provides the students with the procedural knowledge of what needs to be done, rather than focusing on the conceptual understanding of the laboratory exercise. As a result, the chance of metacognitive learning during Task 6 is lower than the potential since the students have not received comprehensive exposure to the concept of acid-base titration prior to the experiment.

As said earlier, removing Part 1 will also remove the first four out of the five preparatory tasks. As observed in Appendix C, the remaining exercise is related to the figure of the titration curve where the students are required to draw the color changes in their respective pH-interval on the figure for the given indicators. Additionally, the first two tasks are calculations related to the initial phase of the standardization, the concentration of KHFt and how much NaOH neutralizes that amount. Table 6 shows that none of the five original preparatory tasks foster higher-order cognitive skills, and therefore, not the last task either. In order to improve cognition in the preparatory work for Task 6, the tasks need to be moved higher up in the hierarchy of Bloom's taxonomy, as illustrated in Figure 6. Since there is no weighing involved, there is no need for the two first calculations. Consequently, there is a possibility to move the tasks up in the hierarchy by introducing new ones for the suggested structure and content.

All the tasks as before foster lower-order cognitive skills. Below are the suggestions for new preparatory tasks, an explanation of their following improvements and a possible solution.

5.4.1 Task 1 – Titration curves

Task: "Draw a figure that shows the titration curves of the weak and the strong acid to be used in the experiment, pH as a function of the relative volume of the titrated strong base. Draw the figure in your laboratory journal."

The solution:

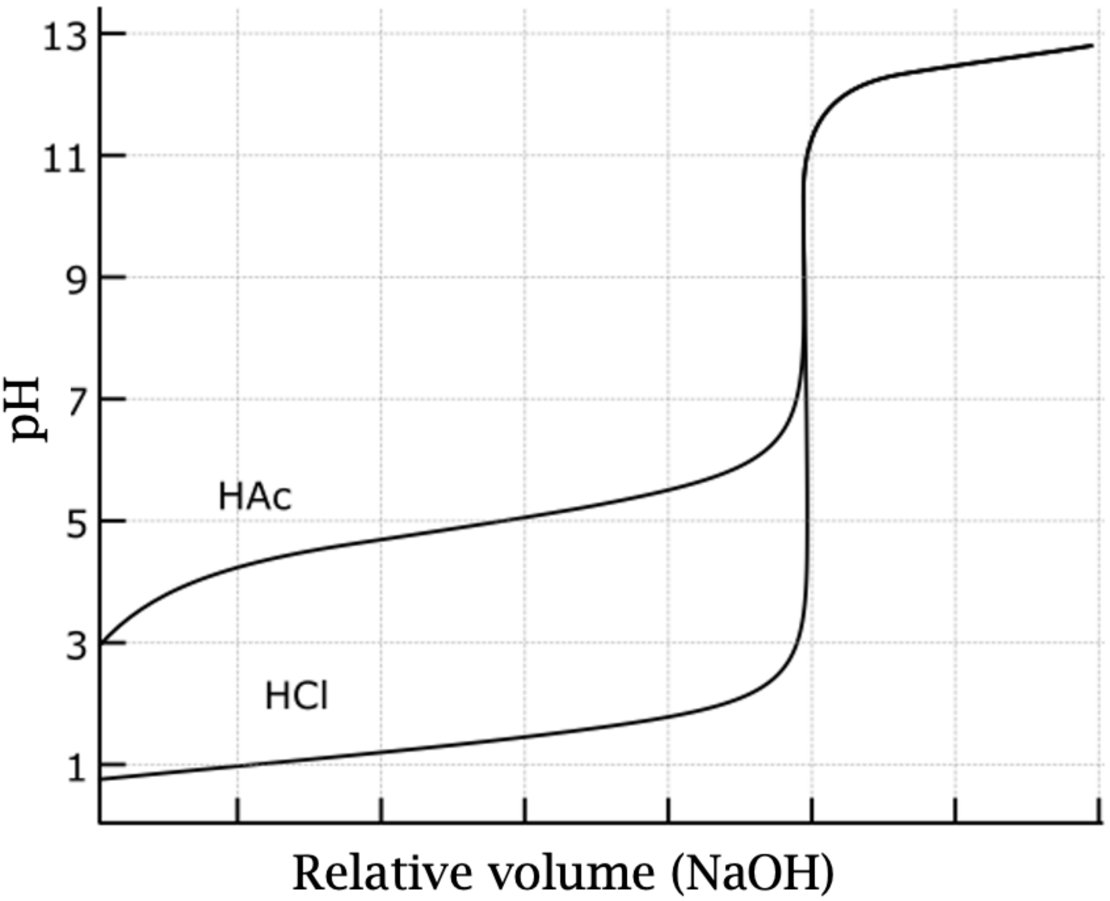


Figure 14: The titration curves of the two different acids titrated against in Task 6. Modified from [3].

This exercise utilizes *Create* since the students must generate the titration curves of the acids, and fosters higher-order cognitive skills. Furthermore, by not providing HAc (weak acid) and HCl (strong acid), the exercise forces the students to read the laboratory manual to find the acids.

The task attains the learning objective, "Titration", since as mentioned in the acid-base part in the Theory section, titration curves are an essential part of understanding acid-base titrations.

5.4.2 Task 2 – Titration curves and indicators

Task: "Phenolphthalein is to be used in the experiment, and two other suitable indicators. Using the given table of indicators below, find two other fitting indicators and draw their color-change in the figure from the previous task."

Table 7: The different indicators available in the laboratory, with their respective pH-interval and color-change. Taken and translated from [57].

Name of indicator	pH-interval	Color-change
Methyl violet	0.2 - 3.0	Yellow - blue - violet
Thymol blue	1.2 - 2.8	Red - yellow
Methyl orange	3.1 - 4.4	Red - orange - yellow
Methyl red	4.4 - 6.2	Red - yellow
Bromocresol purple	5.2 - 6.8	Yellow - purple
Bromocresol blue	6.0 - 7.6	Yellow - blue
Phenol red	6.8 - 8.4	Yellow - red
Thymol blue	8.0 - 9.6	Yellow - blue
Phenolphthalein	8.3 - 10.0	Transparent - red
Thymolphthalein	9.0 - 10.5	Transparent - blue
Alizarian yellow R	10.1 - 12.0	Yellow - red

A possible solution is:

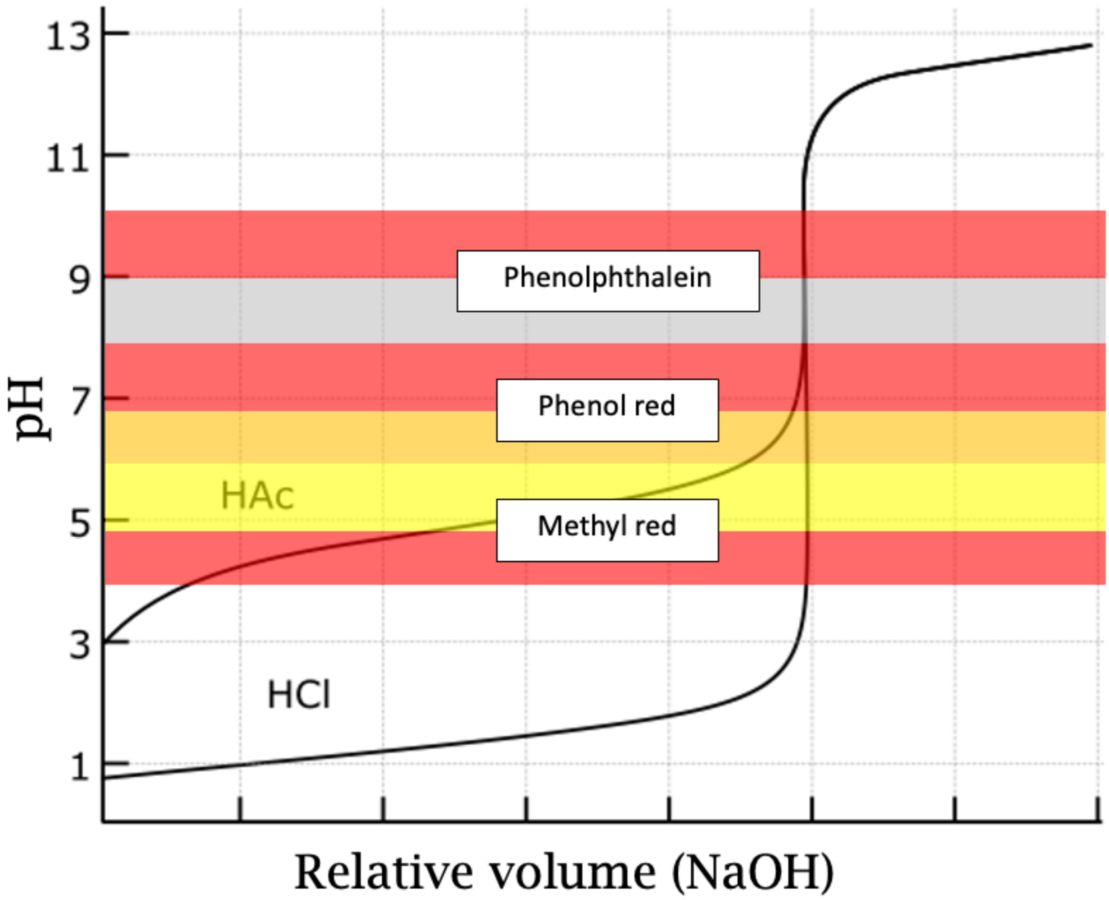


Figure 15: Possible solution to the preparatory task. Modified from [3]

Alternatively, the task can force the students to find the indicators in SI Chemical Data [58] since this is an important tool used in the general chemistry courses. However, then the laboratory must provide all the indicators given in the datasheet.

This exercise utilizes the higher-order cognitive skills, *Analyze* and *Evaluate*, through analysis and evaluation of the two indicators to be used in the experiment.

The task attains the learning objectives, “Titrations” and “Determine the pH in a solution with the help of indicators”. “Titrations” for the same reasons as for Task 1, and “Determine the pH in a solution with the help of indicator” through evaluation and determining the two indicators. Furthermore, indicators, as can be seen in the acid-base titration part in the Theory section, is an important factor in the titration method, and therefore, also a factor in “Titrations”.

As can be seen in the illustration of the procedure of Task 6 in Appendix C, the indicators to be used are provided. As a result, the illustration needs to be updated to exclude the indicators. A suggestion is given below.

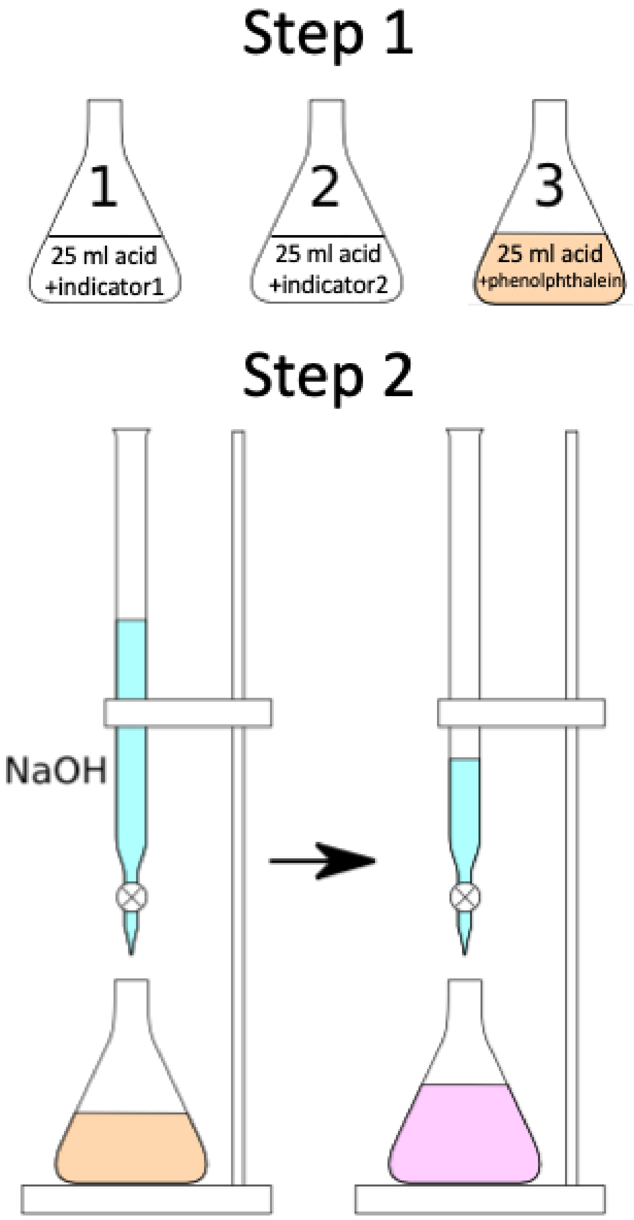


Figure 16: Updated illustration of Step 1 and Step 2 of the experiment for the laboratory manual given in Appendix C. Modified from [3].

The other parts containing the indicators must be removed or modified, i.e. the last paragraph on page number 65, and the paragraphs on page number 68 and 69 (the "Tips!") in Appendix C. The one on page number 65 needs to be removed. The paragraph on page number 68 can be changed to "... three drops of Indicator 1, Indicator 2 and Phenolphthalein..." to fit the names given in Figure 17. The last on page number 69 also needs to be removed, but given as a preparatory question as below.

5.4.3 Task 3 – Indicators

Question: "Which of the indicators will be the best for both acids and can you comment on how the most acidic indicator fits the weak acid?"

Possible solution:

"As can be seen in Figure 17, the most acidic indicator is outside the steepest section of the titration curve of HAc-acid, and will therefore have a pH-interval outside the equivalence point of the acid. Consequently, the color-change will happen too early and not give the correct result."

This task does not foster higher-order cognition, but highlights the most important aspect when choosing an indicator. When choosing a correct indicator, the most crucial part is that the pH-interval is as close to the equivalence point as possible. Since the most acidic indicator is not around the equivalence point for the weak acid, the students need to be aware of this. In the original Task 6, this was given as a tip in the procedure, but modifying it as a preparatory task enhances the chance that the students understand the aspect of indicators and titration curves. Hence, the task attains the learning objectives, "Determine the pH in a solution with the help of indicators" and "Titrations".

5.4.4 Task 4 – Titration reactions

Task: "What are the main reactions happening during the titration for both the weak and the strong acid? Write the reactions in the laboratory journal and indicate on the curves where the reactants are in equal amounts."

Solution:

- Strong acid

$$\mathrm{HCl\ (aq) + NaOH\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l)} \tag{6}$$

or

$$\mathrm{H^+\ (aq) + OH^-\ (aq) \rightarrow H_2O\ (l)} \tag{7}$$

- Weak acid

$$\mathrm{HAc\ (aq) + NaOH\ (aq) \rightarrow NaAc\ (aq) + H_2O\ (l)} \tag{8}$$

or

$$HAc\ (aq) + OH^-\ (aq) \rightarrow Ac^-\ (aq) + H_2O\ (l) \tag{9}$$

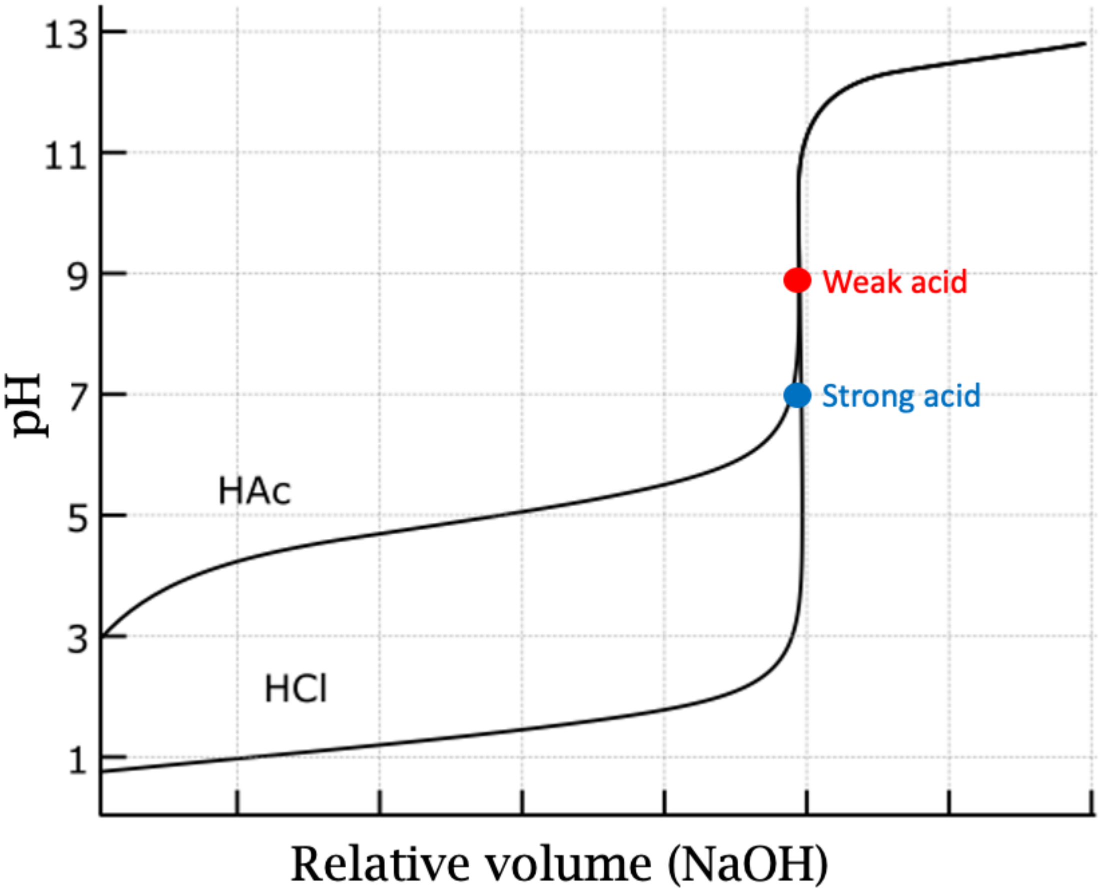


Figure 17: The last part of the task, indicating where the reactant of the acid-base reactions are in equal amounts. Attained from [3].

This exercise fosters the higher-order cognitive skill, *Analyze*, since the students are supposed to differentiate and organize the reactions happening during the titration. Acid-base reactions are the first learning objective and are an essential part of understanding acid-base titration, and therefore, attain the learning objectives, "Acid-base reactions" and "Titrations".

5.4.5 Task 5 – Possible errors and error analysis

Question: "Give three possible errors during the experiment and how to reduce the risks?"

Possible solution:

- Not stopping exactly at the equivalence point. The risk of this error can be reduced by slowly dropping the titrant, drop-by-drop when the analyte initiates the color-change. Furthermore, performing a rapid titration before the main procedure reveals an indication of the volume at the endpoint/equivalence point.

- Misreading the initial or/and final volume of the titration. The risk of this error can be reduced by the same student reading all the volume measurements, as well as not reading the volume at an angle and the top of the meniscus.
- Experimental equipment errors. The risk of this error can be reduced by testing the equipment before performing the titration to check if the equipment is good.

This task, like Task 3, does not foster any higher-order cognitive skills, but is important to ensure accurate experimental results and a successful titration. As stated in the acid-base titration part in the Theory section, sources of error and error analysis are important aspects to understand titration. Task 5, therefore, attains the learning objective, "Titrations", in addition to, "Work precisely in the laboratory".

5.5 Analysis of the new Task 6

The new laboratory task 6 in TMT4110 and TMT4115 presented here is still at the inquiry level of 0.5 since the suggestion is to keep the expository laboratory instruction style. The new preparatory tasks suggested, summarized, attain all the learning objectives and foster the higher-order cognitive skills, *Create*, *Analyze*, *Evaluate*. Consequently, the new analysis of the task is at least as shown in Table 8.

Table 8: Analysis of the old and new laboratory tasks 6 in TMT4110 and TMT4115 in terms of cognitive skill and level of inquiry [4]. Old Task 6 in the table is the analysis in Table 6 in Section 4.1.

Task	Lower order cognitive skill	Analyze	Evaluate	Create	Inquiry level
6 (Old)	✓✓	-	-	-	0.5
6 (New)	✓✓	✓	✓	✓	0.5

The new Task 6 incorporates all the learning objectives and important aspects implied by Førland.

6 Concluding remarks

Task 6 – Titration of strong and weak acid in the general chemistry courses TMT4110 and TMT4115 has been analyzed in terms of level of cognitive skill with the help of Bloom's taxonomy, and interpreted as degree of inquiry. Relevant theory was employed, and the laboratory task has also been performed and mimicked as close to a student's experience as possible. Subsequently, the students performing the laboratory experiment were observed, and interviews were conducted with two laboratory groups both before and after the laboratory exercise.

The relevant theory implied that the laboratory instruction style remains the expository approach. However, the learning objectives needed to be updated by removing the learning objective involving the dissociation constant. Clear communication at all stages of the laboratory exercise was recommended to bridge the gap between student's perceptions of the objectives and what they are expected to learn.

Furthermore, it was also suggested that the content of Task 6 was reduced from a two-part experiment to only Part 2. This both eliminates the time constraints in the experiment and allows for the refinement of the preparatory exercises. As a result, five new preparatory tasks were developed to promote all higher-order cognitive skills, achieve all the learning objectives and encompass all the essential acid-base titration concepts.

Implementing these recommendations is expected to enhance the effectiveness of Task 6 in terms of student learning, outcomes, and understanding. Additionally, enhance the constructive alignment in the laboratory experiment.

6.1 Future work

Further work involves the same procedure with more than a single person on other laboratory tasks in the general chemistry course, or on other courses at NTNU with mandatory laboratory activity for improved student learning. It is important to acknowledge that this work was conducted by a single individual, which may have constrained and limited the quality of the results, especially the interviews and the thematic analysis. The quality of the qualitative analysis method and the interviews is expected to be enhanced by introducing more than one person since this limitation may have restricted the range of perspectives and viewpoints.

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Appendix

A Interview of two laboratory groups

Interviewer: Frode Strømsnes (FS)

A.1 First group

Interviewee: Student 1 (S1) and Student 2 (S2)

A.1.1 Before laboratory:

Date: 01.03.2023

Meeting place: E-S027, Berg
Attendees: Frode Strømsnes (interviewer), Student 1 (interviewee) and Student 2 (interviewee)

FS: Liker dere kjemi og generell kjemi faget?

S1: Liker kjemi generelt, har hatt både Kjemi 1 og Kjemi 2 på videregående. Synes generell kjemi faget er bra satt opp med tanke på det som foreleses og temaet på laboratorieoppavene. Men synes laboratorieoppgavene er veldig repeterende siden studenten har hatt mange av de fra før.

S2: Liker generell kjemi, men i motsetning til S1 så har han bare hatt Kjemi 1 på videregående og synes derfor laboratorieoppgavene er lærerike.

FS: Liker dere denne type laboratorieoppgave, først forarbeid og så gjennomgang av oppgaven?

S1: Videoene er gode nok til at forarbeidet kanskje blir litt overdrevent i noen tilfeller. Videoene er også mer illustrerende i forhold til hva som skal bli gjort på laboratoriet.

FS: Føler dere at forarbeidet er tilstrekkelig med tanke på at dere forstår meningen med laboratorieoppgaven og gjør dere forberedt til forsøket?

S1: Som sagt er forarbeidet i mange tilfeller overdrevent, men er tilstrekkelig nok til å forstå hva man skal gjøre.

S1 og S2: Synes forarbeidet er mer noe man må gjøre enn noe man har lyst til å gjøre. Forarbeidet til oppgave 6 synes de begge var grei og forbredet dem på hva de skal gjøre.

FS: Hva er det meningen at dere skal lære?

S1 og S2: Er ikke klar over læringsmålene, men enige om titrering som teknikk.

A.1.2 After laboratory:

Date: 07.03.2023

Meeting place: Outside room 104, Metallurgy
Attendees: Frode Strømsnes (interviewer), Student 1 (interviewee) and Student 2 (interviewee)

FS: Likte dere oppgaven?

S2: Likte oppgaven, men synes at den var litt overdrevent lang.

S1: Var enig i det. Men likte at oppgaven la opp til at man brukte ulike indikatorer og ikke bare en.

FS: Hva var det dere skulle lære av dette forsøket? Hva var meningen med oppgaven?

S1 og S2: De var enige om at den la opp til at de hovedsaklig skulle lære titrering.

S1: Tenkte at den også la opp til at de skulle lære å bruke utstyret brukt under forsøket.

FS: Hvor viktig var manualen når dere gjennomførte oppgaven?

S2: Under første del av oppgaven var det svært viktig å bruke manualen for så sikre at de ikke gjorde noen feil, ettersom de fikk beskjed i videoen om at den kom til å være lang og effektivitet var viktig. Derfor ville de heller gjøre den mest mulig riktig enn å plutselig slurve slik at de måtte gjøre noe flere ganer.

S1 og S2: Gikk mer og mer bort fra manualen når de fikk titrering mer i fingrene og ble komfortable.

FS: Hva ville dere gjort for å forbedret oppgaven?

S1 og S2: Måtte ærlig innrømme at den var meget lang og synes den kunne blitt gjort noe kortere. Av den grunn ble siste del av oppgaven noe mer slurvete og unøyaktig enn første del av oppgaven. Den ble til slutt mer krig mot tiden enn å konsentrere seg om hva som foregikk underveis.

FS: Sett i et større bilde, hvordan ville dere designet en laboratorieoppgave for at den skulle oppfylt deres behov?

S1: For å forbedret oppaven burde den være kortere.

S2: Synes at det var greit at det var mange titreringer slik at studenten skjønte det, men synes alikevell at den var lang.

S1: Liker at forarbeidet gjør dem klar til forsøket, og at sammen med videoen har de en oversikt over hva de skal gjøre og hva som er viktig å tenke på underveis.

S2: Enig i det.

S1: Synes også at det ikke er noe rapportskriving etter laboratorieoppgaven.

S2: Synes det hadde vært fint med noen spørsmål til refleksjon i etterkant med laboratorieassistentene slik at man sikrer at man har forstått tema.

A.2 Second group

Interviewee: Student 3 (S3), but the fourth student had long-time sickness and was, therefore, sick on both occasions.

A.2.1 Before laboratory:

Date: 06.03.2023

Meeting place: Outside room 104, Metallurgy
Attendees: Frode Strømsnes (interviewer) and Student 3 (interviewee)

FS: Liker du kjemi?

S3: Liker ikke kjemi veldig godt og har ikke hatt noe kjemi på videregående, men synes av den grunn laboratorieoppgaver er lærerike.

FS: Hva er det du liker/ikke liker med laboratoriearbeid?

S3: At studenten får både lære teorien i undervisningen, men også se det i praksis på laboratoriet. Liker også at laboratorieassistenten er aktivt tilstede for at de kan stille spørsmål som igjen fremmer læringen. Dette har hjulpet både for å forstå hva som skjer på laboratoriet, men også for læringen av de ulike temaene.

FS: Føler du at forarbeidet er tilstrekkelig med tanke på at du forstår meningen med laben og gjør at du kommer forberedt til forsøket?

S3: Ettersom studenten ikke har hatt noe laboratorieaktivitet i kjemi fra før synes personen at forarbeidet var bra nok til å skjønne hva de skal gjøre under forsøket, mer enn hva som er meningen med forsøket. Og videoene som blir vist er mer for å forstå HMS tilknyttet til oppgaven.

FS: Hva tenker dere er meningen med dette forsøket? Hva er det meningen at dere skal lære?

S3: Er ikke sikker, vet ikke hva som er læringsmålene.

A.2.2 After laboratory:

Date: 07.06.2023

Meeting place: Outside room 104, Metallurgy
Attendees: Frode Strømsnes (interviewer) and Student 3 (interviewee)

FS: Likte du oppgaven?

S3: Likte oppgaven med tanke på det fysiske med at du så fargeendringen under titreringen.

FS: Hva var det dere skulle lære av dette forsøket? Hva var meningen med oppgaven?

S3: Man skulle gjennom oppgaven lære titrering og lære å bruke utstyret. Studenten synes ikke oppgaven vil være noe relevant for fremtiden. Læringsmålene var ikke tydelige før, under eller etter oppgaven var gjennomført. Studenten var fremdeles ikke klar over hva som var læringsmålene.

FS: Hvor viktig var manualen når dere gjennomførte oppgaven?

S3: Under første del av oppgaven var det viktig å bruke manualen, det vil si under veiing og første titrering. Men ettersom man skal gjøre dette flere ganger under forsøket ble manualen mindre og mindre brukt når man får kontroll på titreringen. Men gjennom oppgaver generelt er manualen veldig viktig og noe man følger hele tiden slik at man ikke ender opp med å gjøre feil og deretter være lenger på laboratoriet.

FS: Hva ville du gjort for å forbedret oppgaven?

S3: Etter litt betenkningstid kom studenten frem til at det å gjøre oppgaven om til ett problem slik at man slipper så mange titreringer. Dette ville gjort at studentene som gjennomfører oppgaven ikke blir så opphengt i tiden den tar, men heller konsentrerer seg mer om å gjøre den nøyaktig.

FS: Sett i et større bilde, hvordan ville dere designet en lab for at den skulle oppfylt deres behov?

S3: Ville ikke hatt noe etterarbeid etter forsøket ettersom den er på 4 timer og tar lang tid allerede. Men derimot, å ha forarbeid for å forberede seg til laboratoriet er bra og passer studenten fint. Studenten synes laboratorieforsøkene er bra ettersom hen ikke har hatt noe kjemi fra før, og det at laboratorieassistentene er lett tilgjengelige gjør at man kan stille spørsmål om man skulle lure på noe.

B Thematic analysis of the interviews

B.1 First group

B.1.1 Before laboratory:

Kommentarer:	Svar:	Kode:
At Person 2 sa at han liker kjemi kan ha noen med omstendighetene å gjøre, at Person 1 svarte først og at intervjuet er nytt for studenten.	Begge liker kjemi generelt og TMT4110. Person 1 - kjemi 1 og 2, Person 2 - kjemi 1. Begge liker kjemi og synes faget er bra satt opp med tanke på det som foreleses og temaet på laboratorieoppgavene. Men person 1 synes at labene er repeterende siden han har hatt det meste til nå fra før, men derimot person 2 synes at laboratorieoppgavene er mer lærerike ettersom han ikke har hatt det før.	Liker kjemi, Forelesning og lab, Mye kjemi = Repeterende, Mindre kjemi = lærerikt
	Videoene er gode nok til at forarbeidet kanskje blir litt overdrevent i noen tilfeller. Videoene er mer illustrerende i forhold til hva som skal bli gjort på laboratoriet.	Video -og forarbeidharmoni, Illustrerende video
	Forbarbeidet er i mange tilfeller overdrevent, men er tilstrekkelig nok til å forstå hva man skal gjøre. De synes forarbeidet er mer noe man må gjøre enn noe man har lyst til å gjøre før lab. Forarbeidet til oppgave 6 synes studentene var grei og forbredet dem på hva de skal gjøre.	Forarbeid, Vilje
Det som var bra at forarbeidet illustrerte hva de skal gjøre, men er ikke dette hva videoen og vitass skal gjøre?	Er ikke klar over læringsmålene, men enige om titrering som teknikk.	Læringsmål

Figure 18: How codes were generated for the first interview of the first group, with additional comments.

B.1.2 After laboratory:

Kommentarer:	Svar:	Kode:
	Både person 1 og person 2 likte oppgaven, men de synes begge at den var litt overdrevent lang. Person 1 likte at oppgaven la opp til at man brukte ulike indikatorer, og ikke bare en.	Lang lab, Likte oppgaven
	De var begge enige om at den skulle hovedsaklig lære de titrering, men person 1 tenkte kanskje at den også skulle være med på å lære å bruke utstyret brukt under forsøket.	Studentenes antatte læringsmål
	Under første del av oppgaven var det svært viktig å bruke manualen for å sikre at de ikke gjorde noe feil, ettersom de fikk beskjed i videoen om at den kommer til å være lang og effektivitet var viktig, i følge person 2. Derfor ville de heller gjøre den mest mulig riktig enn å plutselig slurve slik at de måtte gjøre noe flere ganger. De var enige om at de mer og mer gikk bort fra manualen når de fikk titrering mer i fingrene og ble komfortable.	Manualen, Lang lab, Tid
	De måtte ærlig innrømme de synes oppgaven var meget lang og at de synes den kunne blitt gjort noe kortere, og av den grunn ble siste del av oppgaven noe mer slurvete og unøyaktig enn første del av oppgaven. Den ble til slutt mer krig mot tiden enn å konsentrere seg om hva som faktisk foregikk underveis.	Lang lab, Tid
Til og med en som ikke har hatt mye kjemi før og synes den er lærerik, mener at laben var lang	For å forbedret denne oppgaven var begge studentene enige om at den bør bli gjort noe kortere. Ettersom person 2 ikke har hatt like mye kjemi før synes han det var greit at det ble gjort mange titreringer slik at studenten skjønte det, men han synes i likhet med person 1, med enda mer erfaring i kjemi, at den allikevel var lang. De liker begge at forarbeidet gjør dem klar til oppgaven, og at sammen med videoen har de en oversikt over hva de skal gjøre og hva som er viktig å tenke på underveis. Person 1 synes det er bra at det ikke er noe rapportskriving etter lab, men person 2 synes det hadde vært fint med noen spørsmål til refleksjon i etterkant med labassistentene slik at man sikrer at man har forstått tema.	Lang lab, Mindre kjemi = lærerikt, Forarbeid, Forarbeid & video, Etterarbeid

Figure 19: How codes were generated for the second interview of the first group, with additional comments.

B.2 Second group

B.2.1 Before laboratory:

Kommentarer:	Svar:	Kode:
Her, i likhet med forrige intervju, mindre kjemi medfører at laben er mer lærerik	Liker ikke spesielt kjemi veldig godt og har ikke hatt noe kjemi på videregående, men synes av den grunn laboratorieoppgaver er lærerike.	Liker ikke kjemi, Lite kjemi = lærerik
	At personen får både lære teorien i undervisningen, men også se det i praksis på laboratoriet. Liker også at laboratorieassistentene er aktivt tilstede for at de kan stille spørsmål, som igjen fremmer læringen. Dette har hjulpet både for å forstå hva som skjer på laboratoriet, men også for læringen av de ulike temaene.	Forelesning og lab, Labassistent
Skal ikke forarbeidet både sørge for at de skjønner hva de gjøre og hva som er meningen med laben, i kombinasjon med video?	Ettersom studenten ikke har hatt noe laboratorieaktivitet i kjemi før synes personen at forarbeidet var bra nok til å skjønne **hva de skal gjøre under forsøket, mer enn hva som er meningen med forsøket**. Videoen som blir vist er mer for å forstå HMS tilknyttet oppgaven.	Forarbeidsmål, Video
	Er ikke klar over læringsmålene.	Læringsmål

Figure 20: How codes were generated for the first interview of the second group, with additional comments.

B.2.2 After laboratory:

Kommentarer:	Svar:	Kode:
	Likte oppgaven med tanke på det fysiske med at du så fargeendringen under titreringen.	Likte oppgaven
	Man skulle gjennom oppgaven lære titrering og lære å bruke utstyret. Studenten synes ikke oppgaven vil være noe relevant for fremtiden. Læringsmålene var ikke tydelige før, under og etter oppgaven var gjennomført. Studenten var fremdeles ikke klar over hva læringsmålene var.	Studentens antatte læringsmål, Vilje, Læringsmål
	Under første del av oppgaven var det viktig å bruke manualen, det vil si under veiing og første titrering. Men ettersom man skal gjøre dette flere ganger under forsøket ble manualen mindre og mindre brukt når man får kontroll på titreringen. Men gjennom oppgaver generelt er manualen veldig viktig, og noe man følger hele tiden slik at man ikke ender opp med å gjøre feil og deretter være lenger på laboratoriet.	Manualen, Tid
	Etter litt betenkningstid kom studenten frem til at det å gjøre oppgaven om til ett problem slik at man slipper så mange titreringer. Dette ville gjort at studentene som gjennomfører oppgaven ikke blir så opphengt i tiden den tar, men heller konsentrerer seg mer om å gjøre den nøyaktig.	Tid
	Ville ikke hatt noe etterarbeid etter forsøket ettersom laben er på 4 timer og tar lang tid allerede. Men derimot, å ha forarbeid for å forberede seg til laben er bra allerede og passer studenten fint. Studenten synes laboratorieforsøkene er bra ettersom hen ikke har hatt noe kjemi og lab før, og det at labassistentene er lett tilgjengelige gjør at man kan stille spørsmål om man skulle lure på noe.	Tid, Forarbeid, Mindre kjemi = lærerikt, Labassistent

Figure 21: How codes were generated for the second interview of the second group.

B.3 From codes to themes

Koder:		Tema:
Mye kjemi = repeterende		Motivasjonspåvirkning
Lite kjemi = lærerikt		Konstruktiv harmoni
Liker kjemi		Forventninger og formål
Vilje		
Liker ikke kjemi		
Lang lab		
Likte oppgaven		
Tid		
Mindre kjemi = lærerikt		
Forelesning og lab		
Video og forarbeid		
Video -og forarbeidsharmoni		
Illlustrerende video		
Labassistent		
Forarbeid		
Video		
Manualen		
Forarbeidsmål		
Læringsmål		
Studentenes antatte læringsmål		
Etterarbeid		

Figure 22: How the themes were generated from the codes.

C Laboratory task 6 in TMT4110

Oppgave 6: Titrering av sterk og svak syre

Hensikten med oppgaven er å bestemme konsentrasjonen av en ukjent syre med stor nøyaktighet.

I del 1 skal konsentrasjonen av en NaOH-løsning først bestemmes (løsningen standardiseres) ved å titrere mot en løsning av KHFt ($KHC_8H_4O_4$) hvor konsentrasjonen er nøyaktig kjent. I del 2 skal NaOH-løsningen brukes til titrering av to ukjente syrer, som det dermed er mulig å finne konsentrasjonen til.

HMS
- I denne oppgaven skal dere bruke relativt mye 0,1 M NaOH, så vis aktsomhet selv om løsningen ikke er konsentrert.
- Pass spesielt på når dere fyller byretten og bruk trakt!

Læringsmål

Oppgaven skal gi kunnskaper om og trening i:
- Syre-basereaksjoner
- Titrering
- Dissosiasjonskonstanten for en svak og sterk syre
- Å bestemme pH i en løsning ved hjelp av indikatorer
- Å arbeide nøyaktig på lab

6.1 Teori

6.1.1 Titrering

En løsning av en syre og en base vil nøytralisere hverandre når de blandes. Hvis konsentrasjonen i den ene løsningen er kjent, kan konsentrasjonen i den andre løsningen bestemmes dersom man klarer å avgjøre når støkiometrisk ekvivalente mengder er tilsatt av begge løsningene. Fremgangsmåten kalles titrering.

Om man starter med en løsning av en syre og tilsetter en base, vil blandingens surhetsgrad (pH) endre seg etter hvert som basen tilsettes. Det punktet der tilsatt mengde base er akkurat lik opprinnelig mengde syre (samme antall mol), kalles ekvivalenspunktet. Dersom syren er saltsyre og basen er natronlut, vil man ved ekvivalenspunktet ha en løsning av natriumklorid, som er en nøytral saltoppløsning med pH = 7. Ekvivalenspunktet kan i dette tilfellet bestemmes ved hjelp av en pH-indikator med omslag rundt pH = 7.

Om en svak syre, f.eks. eddiksyre, titreres med natronlut, vil man ved ekvivalenspunktet ha en løsning av natriumacetat, NaAc, som vil være svakt basisk (acetationet er en svak base). I dette tilfelle bør en indikator med omslag i det svakt basiske området brukes. For 0,1 M NaAc kan omslaget beregnes til å skje ved pH = 8,9 (noe lavere verdi for mer fortynnede løsninger), og indikatoren bør dermed ha omslag i pH-området mellom 8 og 10. *Nøkkelen til en vellykket titrering er altså å velge en indikator som slår om så nært ekvivalenspunktet som mulig.*

Oppgave 6: Titrering av sterk og svak syre

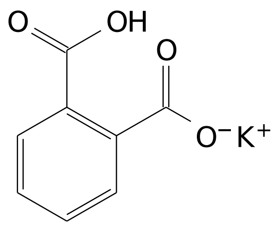
6.1.2 Standardisering av NaOH-løsning

Den enkleste måten å lage en kjent konsentrasjon på er å veie ut et tørt salt, for så å løse det opp i vann til et kjent volum. Dette er imidlertid problematisk med NaOH(s) (natriumhydroksid), siden det lett tar til seg vann fra atmosfæren, og i tillegg reagerer med CO_2 i luften etter ligningen:

$$2NaOH(s) + CO_2(g) \rightarrow Na_2CO_3(s) + H_2O(g) \qquad (6.1)$$

Natriumhydroksid som har vært eksponert for luft vil derfor inneholde fuktighet samt noe natriumkarbonat. I en vannløsning vil NaOH(aq) ta opp CO_2(g) fra atmosfæren på samme måte og endre seg over tid. Dette gjelder spesielt om løsningen står uten lokk. Det er derfor viktig å standardisere konsentrasjonen av natriumhydroksid i løsningen samme dag som den skal brukes til titrering.

Som syre for standardiseringen er det valgt kaliumhydrogenftalat (forkortet KHFt, egentlig formel $KHC_8H_4O_4$, se figur 14). KHFt egner seg godt til å brukes som primær standard da det kan fremstilles i meget ren form og er lite hygroskopisk, og er dermed egnet for nøyaktig utveiing. En KHFt-løsning vil også ha en relativt stabil pH-verdi over tid. Ved oppløsning i vann dissosierer saltet fullstendig:



Figur 14: Kaliumhydrogenftalat

$$KHFt \rightarrow K^+ + HFt^- \qquad (6.2)$$

Hydrogenftalationet, HFt^-, er en relativt svak syre som dissosierer etter likevekten:

$$HFt^- \rightarrow H^+ + Ft^{2-} \qquad (6.3)$$

Syrekonstanten for denne dissosiasjonen er $K_2 = 3.9 \cdot 10^{-6}$. Ved titrering med NaOH-løsning nøytraliseres syren:

$$OH^- + HFt^- \rightarrow Ft^{2-} + H_2O \qquad (6.4)$$

Ved ekvivalenspunktet vil blandingen tilsvare en løsning av saltet NaKFt. Ft^{2-}-ionet er en svak base, så ved ekvivalenspunktet vil løsningen være svakt basisk. En passende indikator for titreringen er fenolftalein, som har omslag ved pH 8,3 til 10,0 (pKa = 9,6).

6.1.3 Innflytelse av CO_2

Karbondioksid løser seg i vann (løselighet ved 20 °C ca. 0,04 mol l^{-1} i likevekt med 10^5 Pa CO_2(g), dette er signifikant i forhold til 0,1 M NaOH), og løsningen blir svakt sur fordi karbondioksid reagerer med vann til karbonsyre:

$$CO_2(aq) + H_2O \rightleftharpoons H_2CO_3(aq) \qquad (6.5)$$

(Denne likevekten er egentlig sterkt forskjøvet mot venstre, siden kun en liten andel av den oppløste CO_2-gassen blir til H_2CO_3 som kan dissosiere. I syrekonstanten som oppgis for karbonsyre er det tatt hensyn til dette, slik at man kan regne som om all oppløst CO_2 foreligger som H_2CO_3.)

Ved f.eks. omslagspunktet for metylrødt (pH ≈ 5) vil protolysesystemet $H_2CO_3 – HCO_3^- – CO_3^{2-}$ i all hovedsak foreligge som udissosiert H_2CO_3 fordi denne syren er meget svak allerede i første trinn (K_1 = $4,2 \cdot 10^{-7}$). Ved videre tilsats av base vil følgende reaksjon finne sted:

Oppgave 6: Titrering av sterk og svak syre

$$H_2CO_3 + OH^- \rightarrow HCO_3^- + H_2O \tag{6.6}$$

Ved pH = 9 (omtrentlig omslagspunkt for fenolftalein), vil systemet i alt vesentlig foreligge som HCO_3^-. Ved titrering av sterk syre med sterk base (uten innhold av karbonat) trengs det bare en dråpe 0,1 M lut for å endre løsningens pH-verdi fra 5 til 9. Med en svak syre til stede, f.eks. oppløst CO_2, vil det være nødvendig med et «ekstra» titrervolum som er ekvivalent med karbonatinnholdet. pH vil endre seg gradvis mens dette ekstra volumet tilsettes, og omslaget blir mindre skarpt.

Tips!

Om overgangen ikke er skarp vil de ulike indikatorene i oppgaven gi ulikt titrervolum. En bør derfor bruke samme indikator ved standardisering av titranten som ved selve målingen. Dette vil ideelt sett gi riktig resultat til tross for CO_2 i titranten.

Ved titrering av en svak syre må en som tidligere nevnt bruke en indikator med omslag i det basiske pH-området. Hvis en titrerer med en indikator med omslag ved høyere pH-verdi enn 9, kan hydrogenkarbonationet HCO_3^- delvis reagere videre:

$$HCO_3^- + OH^- \rightarrow CO_3^{2-} + H_2O \tag{6.7}$$

I ethvert tilfelle vil innhold av karbonat føre til at omslaget blir mer uskarpt enn i et karbonatfritt system.

6.1.4 Valg av indikator

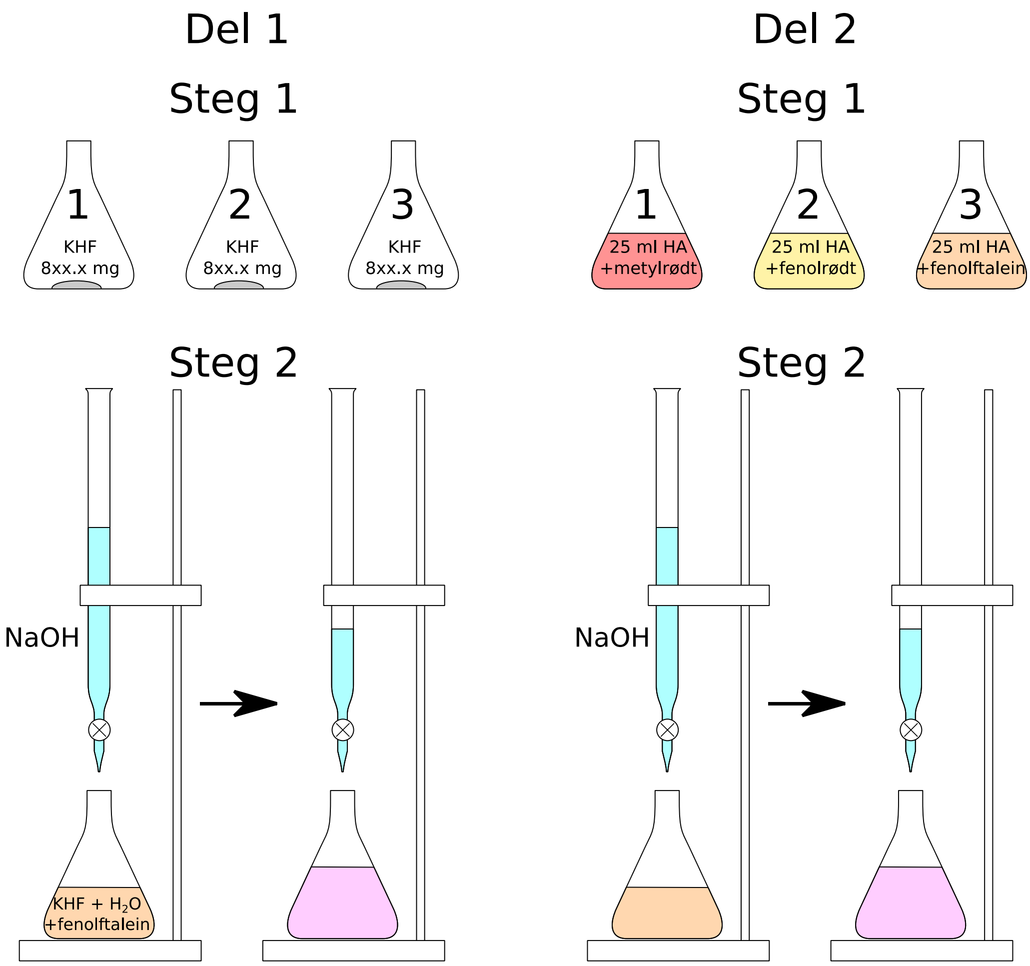
Over ble det forklart at ekvivalenspunktet ved titrering av **sterk** syre med sterk base vil ligge rundt pH = 7 (nøytral løsning). En nærmere undersøkelse viser også at løsningens pH i dette tilfellet vil endre seg fire til fem pH-enheter ved tilsats av en eneste dråpe 0,1 M titrervæske ved ekvivalenspunktet. Ved titrering av sterk syre vil derfor resultatet være tilnærmet uavhengig av valget av indikator så lenge denne har omslag innenfor pH-området ca. 4,5–9,5.

Det ble videre forklart at ved titrering av en **svak** syre med sterk base vil løsningen ved ekvivalenspunktet være basisk, pH > 7. I dette tilfellet må titreringen utføres med en indikator med omslag i det basiske området valgt med sikte på at pH ved omslag skal ligge nærmest mulig pH ved ekvivalenspunktet. Hvis en her isteden bruker en indikator med omslag i det sure området, vil en observere omslag **før** ekvivalenspunktet er nådd, det vil si at en får for lite titrervolum.

Den ene utleverte prøven inneholder en sterk syre (saltsyre), den andre inneholder en svak syre (med oppgitt syrekonstant). Fra hver prøve tas det ut tre paralleller som titreres med henholdsvis metylrødt (omslagsområde 4,4–6,2), fenolrødt (6,8–8,4) og fenolftalein (8,3–10,0). På denne måten vil vi se om vi eksperimentelt kan bekrefte det som er sagt ovenfor.

6.2 Del 1 – Standardisering av NaOH

I del 1 skal en ferdiglaget NaOH-løsning standardiseres. Oppgaveflyten for begge deler av forsøket er skjematisk illustrert i figur 15.



Figur 15: Skjematisk illustrasjon av del 1 og del 2 av forsøket. I del 1 skal konsentrasjonen av en NaOH-løsning bestemmes ved titrering mot en kjent mengde KHFt. I del 2 titreres først en ukjent sterk syre med NaOH-løsningen ved bruk av tre ulike indikatorer, og deretter gjentas dette med en ukjent svak syre.

6.2.1 Utstyr

- Plastflaske (500 ml). Fylles med 500 ml 0,1 M NaOH, som skal standardiseres og deretter brukes til titrering av sterk og svak syre. Hold plastflasken lukket når den ikke er i bruk.

Tips!
Beholderen med NaOH er lufttett, og skrus opp på toppen for å få noe ut.

- Veieskip og spatel til å veie ut KHFt.
- Erlenmeyerkolber (300 ml), til å titrere i. Merk dem 1, 2 og 3 med sprittusj.
- Urglass, til å bruke som lokk på erlenmeyerkolbene som ikke er i bruk.

Oppgave 6: Titrering av sterk og svak syre

- Målekolbe (250 ml), skal stå på plassen med den ukjente syren i.
- Pipette (25 ml) og peleusballong for å overføre den ukjente syren til erlemeyerkolbene i del 2.
- Byrette og magnetrører for titreringen.

Tips!
Alt glassutstyr må være rent. Når det er rent danner vann en hinne, heller enn dråper på overflaten.

Følgende kjemikalier vil brukes:
0,1 M NaOH, KHFt(s), ukjent sterk og svak syre.

6.2.2 Vei ut KHFt

Kaliumhydrogenftalat ($KHC_8H_4O_4$ eller KHFt) skal brukes som primær standard i oppgaven. Ca. 0,8 g skal veies ut i hver av de tre erlenmeyerkolbene. Dette kan gjøres på følgende måte:

1. Ta med veieskip og spatel til grovvektene inne på laben, og vei ut ca. 2,4 g KHFt.

Tips!
Ved vektene er det satt frem KHFt, som på forhånd er tørket ved 110 °C, og er derfor klar til direkte utveiing. Den vil ta til seg fuktighet fra luften og endre vekt om den oppbevares i vanlig atmosfære.

2. Ta med veieskipet (med 2,4 g KHFt), spatel, og de tre erlenmeyerkolbene (merket 1, 2 og 3) til veierommet.
3. Vei veieskipet på finvekt, og noter svaret.
4. Overfør ca. 1/3 av pulveret til den første erlenmeyerkolben, vei veieskipet på nytt og noter svaret. Bruk minst 4 siffer.
5. Gjenta punktet over for den andre og den tredje erlenmeyerkolben. Husk å notere vekten etter hver veiing, også på det tomme veieskipet.
6. Ta med alt tilbake til labplassen, og regn ut vekten til KHFt i hver av de tre kolbene.

6.2.3 Titrering

Løs opp syren i hver av de tre kolbene med 50 ml kokt vann, og tilsett tre dråper fenolftalein i hver kolbe. Bruk urglass som lokk på kolbene, slik at det ikke kommer så mye CO_2 til.

Tips!
Kokt vann benyttes i denne oppgaven fordi det inneholder mindre CO_2 enn destillert vann eller springvann. Det oppbevares på lukket beholder, fordi det ellers vil ta til seg CO_2 fra luften. Av samme grunn blir NaOH-løsningen oppbevart på lukket beholder.

Byretten må være ren før titreringen kan starte,. Skyll også igjennom med litt NaOH-løsning så det ikke er noen rester av rent vann i byretten, og fyll byretten med NaOH-løsningen.

Tips!
Sørg for at det alltid står noe under byretten for å unngå søl. Bruk glasstrakt når byretten fylles.

Sett den første kolben på magnetrøreren og slipp magneten nedi. Les av nivået og begynn titreringen. Ut i fra mengden KHFt i hver kolbe og den omtrentlige konsentrasjonen av NaOH-løsningen (0,1 M), så kan titrervolumet anslås slik at titreringen kan gjøres raskere i starten, og langsommere i nærheten av ekvivalenspunktet.

Tips!

Om det er en luftboble under hanen på byretten må denne fjernes før titreringen kan begynne. Gjør dette ved å åpne hanen helt, og la det renne fort ut, eller ved å knipse forsiktig på byretten.

Tips!

Når en nærmer seg ekvivalenspunktet vil rødfargen som danner seg omkring dråpens nedslag forsvinne langsommere. Nå bør det tilsettes dråpe for dråpe inntil det dannes en svak, permanent rødfarge som ikke forsvinner ved røring og holder seg ett minutt eller mer. En hvit bakgrunn (papir) gjør det lettere å se fargen.

Vaskeflasken kan brukes til å få med væsken som sitter på spissen av byretten og på veggene i kolben. Ved å slippe ut litt væske fra byretten og så skylle dette ned i kolben ved hjelp av vaskeflasken, så er det mulig å tilsette mindre enn en dråpe fra byretten.

Når titreringen er ferdig leses nivået i byretten av.

Gjenta for kolbe 2 og 3.

6.3 Del 2 – Titrering av ukjent syre

6.3.1 Sterk syre

Den sterke syren er utlevert i en 250 ml kolbe, og målet med denne deloppgaven er å finne hvor mange mol syre den inneholder. Det enkleste er å fortynne løsningen opp til merket med kokt vann, for så å bruke en 25 ml pipette til å overføre 25 ml av løsningen tre rene erlenmeyerkolber. Da inneholder hver kolbe 10 % av utlevert mengde syre.

Tilsett så tre dråper av metlyrødt, fenolrødt og fenolftalein til henholdsvis kolbe 1, 2 og 3. Titrer deretter som i del 1.

Tips!

For å finne en helt ukjent konsentrasjon lønner det seg å titrere to ganger, en gang raskt så man vet omtrent hvor mye som behøves, og en gang hvor man titrerer raskt i begynnelsen, for så å titrere dråpe for dråpe når omslagspunktet nærmer seg. Av tidshensyn kan i dette tilfellet kolben med metylrødt titreres raskt, og de to andre mer nøyaktig.

Noter resultatene.

Tips!

Etter titreringen med fenolftalein, når løsningen er så vidt rødlig, prøv å blåse vedvarende mot kolbeåpningen mens kolben ristes. Dette vil føre til at løsningen blir avfarget. Tilsett deretter et par dråper NaOH, og gjenta forsøket så mange ganger som ønskelig. Dette gir kanskje noe innsikt i hvorfor vi bruker kokt vann og lukkede beholdere.

6.3.2 Svak syre

Gjenta forsøket med den svake syren.

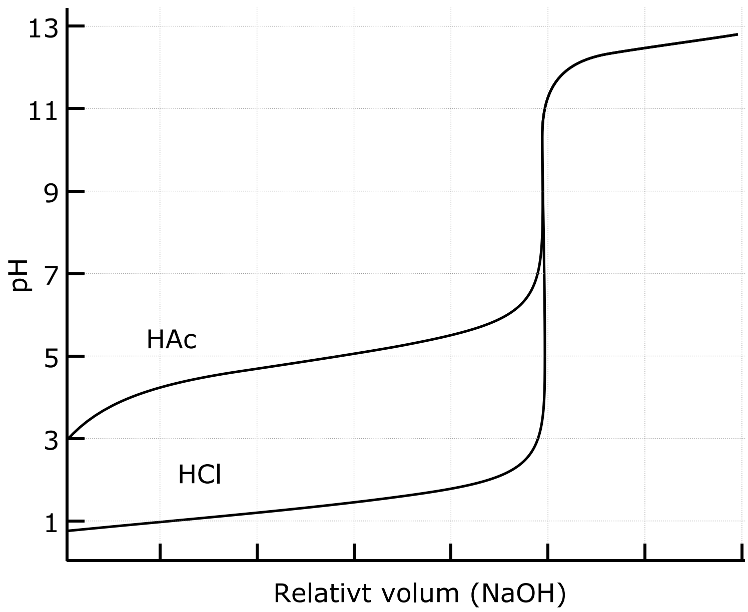
Oppgave 6: Titrering av sterk og svak syre

Tips!

De tre indikatorene har begynnende omslag ved pH = 6 for metylrødt, 7,0 for fenolrødt og 8,5 for fenolftalein. Dette gjør at de vil gi noe ulike resultater ved titrering mot svak syre. Titreringen med fenolftalein vil gi best resultat, da denne har omslag i det basiske området, samt at det var denne indikatoren vi brukte til å standardisere NaOH-løsningen.

6.4 Forarbeid og rapportering av resultater

- Følgende spørsmål skal besvares som en del av forhåndsrapporten som skrives inn i labjournalen *før* oppmøte på lab:
    - Konsentrasjonen av KHFt dersom 0.8 g løses opp i 50 ml vann
    - Hvor mange ml 0,1 M NaOH som må til for å nøytralisere dette
    - Den nederste streken på byretten er 50 ml (men det anbefales at den ikke fylles helt full). Hvor mange gram KHFt kan 50 ml 0,1 M NaOH nøytralisere?
    - Hvorfor blir nøyaktigheten bedre om mengden KHFt er så høy som mulig, men ikke over den utregnet i forrige oppgave?
    - Til høyre er det skissert titrerkurver for NaOH som titreres mot HAc og HCl. Skisser figuren i labjournalen og tegn inn omslagsområde for de tre indikatorene som skal benyttes i del 2.



- På labben må følgende resultater føres inn i labjournalen, og det er foreslått oppsett av tabeller for å rapportere resultatene. Det er anbefalt at dere skriver tabellene inn i labjournalen som en del av forarbeidet.
    - Resultater fra utveiing:

Fullt veieskip	**2/3 fullt**	**1/3 fullt**	**Tomt veieskip**

	1	**2**	**3**
Vekt KHFt			
mol KHFt	mol	mol	mol

Oppgave 6: Titrering av sterk og svak syre

- Resultater fra standardisering:

	1	**2**	**3**
Nivå før:	ml	ml	ml
Nivå etter:	ml	ml	ml
Titrert:	ml	ml	ml
Molaritet:	M	M	M
Gjennomsnitt:			M
% avvik fra snitt:			

- Del 2: Sterk syre:

	Metlyrødt	**Fenolrødt**	**Fenoftalein**
Nivå før:	ml	ml	ml
Nivå etter:	ml	ml	ml
Titrert:	ml	ml	ml
Molaritet syren (etter fortynning):	M	M	M
Antall mol i utlevert kolbe:	mol	mol	mol

- Del 2: Svak syre:

	Metlyrødt	**Fenolrødt**	**Fenoftalein**
Nivå før:	ml	ml	ml
Nivå etter:	ml	ml	ml
Titrert:	ml	ml	ml
Molaritet syren (etter fortynning):			M
Antall mol i utlevert kolbe:			mol

- Kommenter forskjell i titrervolum for de tre indikatorene, og forskjellen i oppførsel på sterk og svak syre.

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