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Drawing Cartoon Strips as a Learning Tool in Fostering the Learning of Titration in Pre-service Chemistry Education

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Abstract: In this study, static visual displays of titration created by the university-level pre-service chemistry education students was investigated. The aim for the students was to learn the theory of titrations, using self-prepared cartoon strips with supportive texts. Attention was paid to the titration cartoon strips students made which were suitable for both learning and teaching purposes. The basis of this study was students' own drawings: students observed and visualized the titration process, and built their own representation of it. Simple models were created using pencil and paper. The goals were to determine how students regard the learning tool, how drawing cartoon strips helps their learning, and what kind of demands can be stated for a clear and pedagogically valuable titration cartoon strip. The research methods used were a questionnaire for students, analysis of students' task reports, and interviews with the course instructors. Students found the visualization of titration using cartoon strips to be motivating and positive, as well as useful for their own learning. They also felt it was a new method for considering titration. It helped them deepen their understanding of titration and assess it to be useful for their work in the future as teachers. According to the course instructors, students needed supportive discussions to accompany their drawing tasks. Furthermore, cartoon strips were a valuable tool for instructors to evaluate learners' understanding and to correct misconceptions.

Keywords: Pre-service Teacher Education, Teaching Practices, Learning Styles, Teaching Methods in Science, Cognitive Skills

1. Introduction

1.1. Visualization

Visualization can be defined as the formation of mental visual images, or the act or process of interpreting in visual terms or of putting into visible form [1]. There are several visualization techniques, including physical models, role-playing, animations, computer models and simulations [2]. Visualization modes can be static (e.g. pictures, physical models and drawings on paper) or dynamic (e.g. animations and simulations) [3]. In visualization, it is important to support the formation of individuals' mental visual images, and thereby their mental models.

For learners, visualization is a novel aspect when studying phenomena. According to the research literature, the use of visualization tools helps learners to increase their conceptual understanding [2, 4] and transfer their understanding to new situations [5]. It also supports learners to advance the formation of their own mental models. Furthermore, when visualization activities challenge students to compare and contrast their understanding, visualization helps students in developing their metacognitive skills [4].

1.2. The Cartoon Strip as a Form of Visualization

The Internet generation is used to visual communication with little amount of text [6]. The frequent use of ICT has taught the Internet generation to integrate text and images, and to move quickly between virtual environments and reality. However, if visual representation, such as an animation, is complex, students may have difficulties in interpreting the representation [7]. Complex animations may overload and confuse students, especially if there is a lack of teacher support. Thus, simple representations have advantages especially when challenging content, as chemistry subjects commonly are, is studied.

Different ways to exploit cartoons in science education have been reported: educational science cartoons, scientoons, concept cartoons and comic strips have been described [6]. Exploiting comic strips resembles the use of storyboards, which are defined as a sequence of drawings and visual representation [8]. Storyboards contain a series of drawings and written explanations, and so it shows the sequential flow of an action. In a chemistry context, storyboards are typically used to represent dynamic processes of phenomena [8]. The term “sequence of pictures” resembles storyboards, and is used to describe a chronological order of pictures that describes a process [9]. In this research, the authors decided to use the term ‘cartoon strip’ to describe the process where dynamic process is described using pictures and text. This was due to the authors’ desire to bring a playful, creative and not-so-serious tone to the students’ drawing process.

When phenomena occur in a timeline, storyboard, or cartoon strip, it helps learners to segment their ideas into phases and thus organize their thinking [8]. However, there are risks in the use of cartoon-type representations [6]. Short and simple text can lead to ambiguous statements, thus the condensed mode of expression should include alternative presentations. To prevent misconceptions, it is necessary to connect other teaching tools to the use of cartoons. It is also important to remind learners of the limitations of the used representation [10].

1.3. Student Creating Visualization

It is typical to study the visualizations of others, but only rarely are learners encouraged to produce their own visual presentations [11]. Students’ pictorial representations are simplifications of their understanding [4], and they have clear advantages in enabling students’ conceptual knowledge, learning to communicate scientific understanding and engaging students in the learning process [12]. When students draw their own cartoon strips, and the process includes verbal description alongside it, information is easier to retain [4]. Furthermore, according to dual coding theory, imagery and verbal processes encode in interconnected memory systems [13]. Thus, semantic and imagery codes both remain in long-term memory, which can lead to more stable memory trace [14].

Drawing pictures and visualizing one’s own thinking fits well in the principles of constructive learning theory, where learners construct or create their own representations of reality. Students can better understand chemical phenomenon by drawing pictures [2, 15].

For learners, visualization is a way to represent their mental models [3]. By drawing cartoon strips, students can use representations suitable for their own thinking and discover possibilities to figure out the idea of the phenomena being studied, such as titration. Drawing appears as a new learning strategy and a communication instrument, which provides students a way to visualize their impression of a phenomenon [2]. Thus, students can better and more thoroughly understand the phenomenon by drawing pictures. Making drawings improves students’ skills to work with different representations, deepens their learning, and teaches them reasoning [11]. The idea in conducting this research was that learners draw cartoon strips by themselves, constructing knowledge in cooperation with other learners and the instructor. A similar method has been reported on in the literature [15].

1.4. Levels of Chemistry Knowledge

Visualizations, such as scientific cartoon strips, can include knowledge of chemistry on multiple levels: macroscopic, symbolic and submicroscopic [2]. By drawing cartoon strips to visualize a chemical experiment or process, different representations of chemical knowledge are linked together. Visualization can be used to connect knowledge on the symbolic and submicroscopic levels with the macroscopic, real-world level.

To develop learners’ understanding of chemistry, a transfer between the macroscopic, submicroscopic and symbolic levels is continually needed [8]. When cartoon strips are drawn to represent titration, the symbolic level (reaction equations, symbols of compounds) obviously links to the macroscopic level (observations). Conceptual understanding often involves understanding the submicroscopic level. The submicroscopic level has to be combined into the cartoon strip, because the explanation of chemical processes are founded on the motion and behavior of particles [3]. As mentioned earlier, lean written expression demands the use of other teaching methods, such as discussion of the student’s cartoon strip.

In a way, student cartoon strips can become like a workbench for students’ thinking and reasoning process. In this, scaffolding by the teacher is needed to clarify learners’ thoughts.

1.5. Our Study

In our study, students created cartoon strips by themselves. This approach was chosen due to the clear benefits of working and constructing with drawing. Moreover, when students create cartoon strips on their own, they are encouraged to be both creative and critical [8].

Generally, students can create visualizations using either classic or new technology [11]. In our study, the authors wanted to simplify the drawing process to ensure focus on chemistry contents. Therefore, the students drew cartoon strips using only pencil and paper.

The students’ task was to create static visual displays of titrations using cartoon strips along with supportive texts. This method was chosen, because visualization is believed to help students advance the formation of their mental models. Using cartoon strips, the instructor can help students process new information, so instructor–learner discussions during students’ drawing process was a vital component in the laboratory work [2]. Since participants in this study were pre-service chemistry teachers, it was important to pay attention to the application of drawing cartoon strips for learning and teaching purposes.

The basis of this study was students' drawings. Learners observed and described the titration process, building their own representations – and mental models – using pencil and paper, and explained the phenomena using this simple model. The purpose was to determine how students regard this learning tool, if and how drawing cartoon strips helps their learning, and which properties make cartoon strips clear and pedagogically valuable. The authors also wanted to clarify if students' learning style (visual–verbal, visual–nonverbal, auditory–verbal and kinesthetic–tactile), and the learning theory (behavioristic, humanistic, cognitive and constructive) closest to students' thinking affects students' experience of the approach.

2. Research Questions

The context of our research was chemistry teacher education. The participants in this research were pre-service chemistry teachers, including both major and minor students in chemistry education. The research questions were formulated as follows:

(1) How do pre-service chemistry teachers regard the visualization of titration using cartoon strips they draw?
(2) How does drawing cartoon strips help pre-service chemistry teachers' learning when studying titration methods?
(3) How do students' ideas of their own learning style (visual–verbal, visual–nonverbal, auditory–verbal, kinesthetic–tactile) and closest learning theory (behavioristic, humanistic, cognitive, constructive) affect their view on the method used?
(4) Which qualities and properties make cartoon strips clear and pedagogically valuable?

3. Methods

3.1. The Course

This study was carried out in connection with the course KEMS701 Instruction in Experimental Chemistry (5 ECTS), in the Department of Chemistry at the University of Jyvaskyla, Finland. The course is part of advanced studies of chemistry for pre-service chemistry teachers. Students in the course are both chemistry majors and minors, and this is their first specific laboratory course in chemistry education studies. The course includes weekly laboratory work in small groups (11 sessions of four hours each, for a total of 44 hours). The course also includes learning tasks, a laboratory safety lecture, written laboratory reports, and teaching visit for lab work. For the lab work visit, school classes come to university premises where chemistry laboratory experiments are carried out by the guidance of the teacher students.

The course includes demonstrations, laboratory experiments, and writing laboratory experiment instructions for school students. The working method is mainly pair work. The course includes lots of peer–peer, instructor–student and instructor-led discussions. The learning objectives of the course are connected to chosen chemistry content, as well as to aspects of chemistry education. Laboratory experiments are discussed from the perspective of learning and teaching. During the course, students are introduced to teaching using laboratory experiments, and to the challenges of learning-by-doing laboratory experiments.

The course includes three titrations: acid–base titration (determination of lactic acid concentration of soured-milk products), precipitation titration (determination of salinity of food samples) and redox titration (determination of iron content of iron tablet). Students draw cartoon strips for all the titrations. In the first titration with lactic acid, instructor shows the idea of drawing cartoon strips: the phases of titration, and thus the theory of titration, are visualized using cartoon strips. Each student creates his/her own cartoon strip based on given instructions. Students are guided to draw four panels in a strip: (1) at the very beginning of titration, (2) during the titration on salinity, (3) at the equivalence point of titration and (4) at the end point of titration. The idea of the cartoon strip in explaining the theory of titration is also discussed with students. During the second titration, students draw cartoon strips with the guidance of the instructor, but more independently. After the third titration on redox titration, students are guided to explain the theory and phases of implemented titration using cartoon strips. This is one of students' learning tasks in the course. Later in the course, another learning task is to read supplementary material about complexometric titration (determination of water hardness of tap water) and explain the theory and phases of this titration using a cartoon strip. By reiterating the procedure, students are prepared to transfer their understanding to a new situation.

3.2. Participants and Data Collection

A total of 22 pre-service chemistry teachers participated in the course, and 21 of them were involved in this voluntary research. The data were collected during the autumn term of 2018.

This research included questionnaires for pre-service chemistry teachers at the beginning (Q1) and end (Q2) of the course. Questionnaires included both open questions and Likert-scale statements. The aim was to clarify the students' opinions, ideas and experiences regarding the cartoon strip method.

Two of the course's learning tasks, both concerning titrations and described earlier, were included in this research. By analyzing pre-service chemistry teachers' learning tasks, the authors wanted to determine how the students understood the chemistry content of titrations, how they succeeded when their aim was to draw an illustrative and explanatory cartoon strip, and what kind of pedagogical solutions pre-service chemistry teachers created to describe titration. The cartoon strips were analyzed to identify criteria for clear and pedagogically meaningful ways to describe the process of titration.

All three instructors of the course were interviewed to determine their impressions. The aim was to sort out their ideas and experiences about drawing cartoon strips when titration is studied. The interviews lasted 10 to 15 minutes. The interviews were recorded and, after the transcripts were completed, the dictation file was destroyed. The interview questions were as follows:

1) Please briefly describe your education and work history.
2) What do you have to take into account as a teacher in the teaching of titration?
3) In your opinion, which are the challenges of teaching titration?
4) What are the benefits of using the drawing of cartoon strips as a teaching method?
5) What should be taken into account when using cartoon strips to teach this subject?
6) How do you see the pre-service chemistry teachers' views on teaching titration with cartoon strips?
7) How would you develop teaching using this method in the future?

3.3. Data Analysis

Answers to open questions of questionnaires and interviews of the course instructors were analyzed using data- based content analysis. Key themes and ideas were identified.

Quantitative survey data (5-point Likert-scale questions, 1 = strongly disagree, 5 = strongly agree) were analyzed statistically using SPSS Version 26. Mean values (M), standard deviations (SD) and Cronbach's alphas were calculated. In addition, correlations were analyzed to measure the effect of pre-service chemistry teachers' learning style (visual–verbal, visual–nonverbal, auditory–verbal and kinesthetic–tactile) and the closest learning theory (behavioristic, humanistic, cognitive and constructive) to how they experienced the method used in this research.

Students' learning tasks were categorized based on two criteria. In the pre-service chemistry teachers' drawings, the following aspects were analyzed: (1) the correctness of the chemistry content and (2) the clarity and pedagogical value of the cartoon strips. In analyzing the process, the requirements for a correct, clear and pedagogically usable way to express titration using a cartoon strip were created based on students' output. In the analysis, the authors identified with nine criteria for correctness of chemistry content and 11 criteria for the clarity and pedagogical value of the cartoon strip.

4. Results

4.1. Questionnaire for Students, Open Questions

Students described how they experience their knowledge and skills related to titration. In the content analysis based on the students' answers, their theoretical knowledge and practical skills were classified as good/rather good and weak. The same question and analysis was repeated at the beginning (Table 1), and end of the course (Table 2). As was assumed, students' experience of their knowledge and skills evolved during the course. For example, seven students' evaluation of both practical skills and theoretical knowledge were analyzed as good/rather good at the beginning of the course. By the end of the course, the number of students rose to 18.

Table 1. *Students' (n = 20) experience of their theoretical knowledge and practical skills of titration at the beginning of the course.*

	Good/rather good practical skill	Weak practical skills
Good/rather good theoretical knowledge	7	3
Weak theoretical knowledge	1	7

Table 2. *Students' (n = 19) experience of their theoretical knowledge and practical skills of titration at the end of the course.*

	Good/rather good practical skill	Weak practical skills
Good/rather good theoretical knowledge	18	0
Weak theoretical knowledge	1	0

At the end of the course, almost all of the students considered their theoretical knowledge and practical skills to be good. However, some students reported that while they felt some mastery of the subject, knowledge on other areas of titration could be strengthened. These included deepening their theoretical knowledge, practicing the drawing of the titration curve, getting a better idea of how to apply implemented titrations, and planning titration.

At the end of the course, students were asked to give their opinion on the cartoon strip method. The results of the content analysis are stated in the following section.

Question 2: The course utilized the drawing of the cartoon strips to help internalize the theory of titration. What opinions do you have about the method used?

(a) Drawing the cartoon strips helped to understand the idea of titration (f = 26)

It helped to understand titration (f = 9)

Example responses:

A12: It illustrates titration.

It helped to understand the theory of titration (f = 9)

Example responses:

A13: It helped to understand what the reactions are all about.

It helped to understand the phases of titration (f = 4)

Example responses:

A11: The cartoon concretized the steps of titration well.

It helped me understand titration more deeply (f = 4)

Example responses:

A14: It helped to structure my thinking and to see the overall picture of titration.

(b) Drawing the cartoon strips benefited the students' work as teachers (f = 2)

Example responses:

A17: It makes my work as a teacher easier.

(c) Other opinions (f = 6)

Examples of responses:

A3: It takes time, but so does writing.

A10: Drawing cartoon strips also requires a good explanation.

A18: It certainly works well for visual learners.

Drawing cartoon strips in the context of titration theory helped students discuss the details more thoroughly. In a way, the method forced students to consider all the details of titration. Students mentioned that it also helped structure and guide their thinking to create an overall picture and deeper understanding of titration. All in all, drawing a cartoon helped to better understand of various aspects of titration. Some pre-service chemistry teachers had also already thought about using the method as a tool in their own teaching.

Students were asked to describe how, if at all, the method helped their learning.

Question 3: How did the method of drawing cartoon strips, help your own learning?

(a) It helped students to understand more precisely what happens during titration (f = 9)

Example responses:

A9: It helped to understand more clearly the process of titration.

(b) It helped students to outline titration step by step (f = 8)

Example responses:

A18: It helped to better understand what is really happening at different phases of titration.

(c) It helped students to think more deeply about titration (f = 8)

Example responses:

A8: It helped to better understand what is happening in practice.

(d) It helped students to understand the function of the indicator (f = 6)

Example responses:

A13: It helped to understand the causes of the color changes.

(e) It helped students to associate the three learning levels of chemistry (f = 3)

Example responses:

A16: It was easy to add reaction equations to the cartoons.

Drawing cartoon strips made it easier for students to learn what happens during titration. By drawing pictures, they saw what happens at different phases of the process. The strips helped them understand the content of chemistry and developed their metacognitive skills through discerning their thinking process to achieve an explicit general view of titration. Moreover, some of the students associated the three learning levels of chemistry (submicroscopic, macroscopic and symbolic) with each other.

Students also described what should be paid attention to, when cartoon strips in the context of titration are drawn.

Question 4: When cartoons like this are drawn, what kind of things should you pay attention to?

(a) Clearly presenting the topic (f = 26)

Example responses:

A4: For clarity: easy-to-read, pictures that are large enough, additions and notes marked beside the sequence.

A9: It has to be simple enough.

(b) Technical issues: the cartoon is big enough (f = 6)

Example responses:

A3: Draw a big enough picture. The technical quality of the picture is not essential, if the picture is clear.

(c) Teacher-related issues (f = 5)

Example responses:

A14: The essential thing is that the students do not create misconceptions based on the model.

A15: The teacher has to explain the cartoon thoroughly.

(d) Others (related to the chemistry content or don't know) (f = 5)

Example responses:

A16: What is happening to the indicator.

When drawing a cartoon, according to the students, it is important that the matter is presented clearly. Students mentioned that large visualizations are easier to interpret than small ones are. The amount of information in the strip should be limited. It is also important to pay attention to the clarity and position of the texts. Teachers should discuss and rationalize the cartoons to avoid misunderstandings. Also, teachers should pay attention to how to mark different substances in pictures, such as indicators.

4.2. Questionnaire for Students, Likert-scale Questions

Table 3 presents results of students' responses to Likert-scale statements.

Table 3. *Students' responses to Likert-scale statements, at the beginning (n = 20) and at the end (n = 19) of the course, means (M) and standard deviations (SD).*

Likert-scale statement	**At the beginning, Q1 (M±SD)**	**At the end, Q2 (M±SD)**	**Remainder (Q2 - Q1) (M)**
I have performed several titrations myself	2.40 ± 1.54		
I have taught titrations either in practice school or school	1.40 ± 1.10		
I can name all the titration equipment	3.35 ± 1.31	4.47 ± 0.77	1.12
I handle all the stages of titration in practice	2.95 ± 1.28	4.63 ± 0.50	1.68
I have mastered titration mathematically	3.10 ± 0.91	4.42 ± 0.61	1.12
I can explain what is happening at the end point of titration	3.15 ± 1.04	4.68 ± 0.48	1.53
I have mastered different titrations: acid-base titration	3.15 ± 1.46	4.68 ± 0.48	1.53
redox titration	2.40 ± 1.35	4.26 ± 0.93	1.86
precipitation titration	2.05 ± 1.28	4.16 ± 1.01	2.09
complexometric titration	2.00 ± 1.26	3.33 ± 1.28	1.33
conductivity titration	1.85 ± 1.09	2.58 ± 1.12	0.73

Likert-scale statement	At the beginning, Q1 (M±SD)	At the end, Q2 (M±SD)	Remainder (Q2 - Q1) (M)
back titration	1.80 ± 1.11	2.84 ± 1.26	1.04
Drawing titration strips helped my learning process		4.79 ± 0.42	
Drawing titration strips was motivating		4.37 ± 0.68	
Drawing titration strips was funny		4.26 ± 0.73	
Drawing titration strips clarified my thoughts		4.84 ± 0.37	
Drawing titration strips was a workable learning method		4.74 ± 0.45	
Drawing titration strips did not help my learning process		1.32 ± 0.58	
I will use this method in the future in my own teaching		4.63 ± 0.60	
I find that suitable learning style for me is: visual–verbal		3.84 ± 0.83	
visual–nonverbal		3.89 ± 0.88	
auditory–verbal		3.16 ± 1.26	
kinesthetic–tactile		3.68 ± 1.06	
The closest learning theory for my impression is: behavioristic		2.37 ± 0.96	
humanistic		3.42 ± 0.96	
cognitive		3.74 ± 0.93	
constructive		3.89 ± 0.66	

+ 1 = strongly disagree, 2 = disagree, 3 = neutral opinion, 4 = agree, 5 = strongly agree. In the column on the right, the change of students' answers during the course is described by calculating the remainder of means at the beginning and at the end of the course.

In Q1 (questionnaire at the beginning of the course), Cronbach's alpha coefficient ranged between 0.94 and 0.95, meaning the scales displayed excellent internal consistency. In Q2 (at the end of the course), Cronbach's alpha coefficient ranged between 0.78 and 0.82, meaning the scales displayed acceptable internal consistency. Students felt their skills were clearly improved after the course, as was assumed. In particular, students' impression of their knowledge of other titrations apart from acid-base titration was weak at the beginning of the course. Students felt that they mastered redox (mean ranged from 2.40 to 4.26, remainder 1.86) and precipitation titration (mean ranged from 2.05 to 4.16, remainder 2.09) much better after they had implemented those. Yet students' impression of their knowledge concerning conductivity (mean from 1.85 to 2.58, remainder 0.73) and back titration (mean from 1.80 to 2.84, remainder 1.04) increased even though those titrations were not executed or even discussed during the course.

Students mostly agreed with the statements such as "Drawing titration strips clarified my thoughts" ($M = 4.84$), "Drawing titration strips helped my learning process" ($M = 4.79$), and "Drawing titration strips was a workable learning method" ($M = 4.74$). The results are encouraging for the authors: the drawing of cartoon strips as a tool helps students' cognitive learning process. In addition, students mostly felt that the method was motivating and enjoyable.

In questionnaire Q2, students were asked how they felt about different learning styles (visual–verbal, visual–nonverbal, auditory–verbal and kinesthetic–tactile) related to their learning, and which learning theory (behavioristic, humanistic, cognitive and constructive) was closest to their own way of learning. No correlation was found between students' learning style and their experience of the method used in this research. Instead, a weak correlation was found between the students' closest learning theory and their experience of the cartoon strip method. Students who felt constructive learning theory was most adequate to describe their own learning approach, abbreviated as "closest" by students, reported that drawing titration cartoon strips clarified their thoughts ($r = .45$, $n = 19$, $p = .05$), found drawing the strips to be motivating and fun, and stated they will use the method later as a teacher ($r = .45$, $n = 18$, $p = .06$). However, the results were not statistically significant and so no conclusion can be made without research among larger groups of students.

4.3. Learning Tasks

The main point of analysis of learning tasks was to create criteria for a proper cartoon strip. In analyzing the process, the authors identified nine criteria for correctness of chemistry content and 11 criteria for the clarity and pedagogical value of the cartoon strips. Based on the analysis, a chemically proper cartoon strip contains (1) compounds of the solution at the beginning of titration, (2) the color of the solution at the beginning of titration, (3) adding the titrant, (4) the reaction equation, (5) the essential chemical reaction type, such as oxidation and reduction, or the formation of a complex compound, (6) compounds of solution at the end of titration, and (7) the color of solution at the end of titration. In addition, (8) in the verbal explanation, the terms should be used properly, and (9) the principle of titration described correctly. When the clarity and the pedagogical value of the cartoon strip are evaluated, an adequate strip (1) is large enough, (2) contains only the essential compounds of titration, (3) includes different colors (4) and they are logically used, (5) clearly represents adding the titrant, (6) includes verbal explanation (7) and it is logically placed in the strip, (8) is framed clearly and (9) concisely, and (10) clearly shows the difference between the equivalence point and end point (11) which are also verbally highlighted.

The results of the analysis are stated in Table 4. Most of the students' strips were done with made with great dedication and included precise verbal explanation, while some individual cases were meager and included errors. As such, it is not surprising that undergraduate students have misconceptions in the content they have already studied [15]. The great majority of students marked reagents, colors and titrant in the strips.

The differences in the strips came up when verbal explanations, the use of colors and the expressions of reaction equations were compared. As a group, the students managed better in the later learning task.

Table 4. *Results of analysis of students' learning tasks, means (M) ± standard deviations (SD). Maximum points were 9 + 11 = 20.*

	Redox titration (M ± SD)	Complexometric titration (M ± SD)
Correctness	6.7 ± 2.2	7.9 ± 1.7
Clarity and pedagogy	6.4 ± 2.8	7.6 ± 2.3
Total	13.1 ± 4.3	15.6 ± 3.6

Based on the analysis, the criteria for proper titration cartoon strip were as follows:

1) The compounds at all phases of titrations are stated.
2) To achieve better clarity, states of compounds are presented only when essential (e.g., precipitation reaction).
3) The strip includes no reactants which do not react in titration.
4) The adding of the titrant is shown in the cartoon, in all appropriate strips.
5) The reaction equations and essential chemical reactions (e.g. the formation of complex compounds) of titration are included in the strip.
6) A concise and clear verbal explanation is stated logically placed in the strip, and the difference between the equivalence point and end point is highlighted.
7) The colors of the titration solution in the phases of titrations are stated, also by using corresponding colors in the pictures.
8) The strip is large enough.

Figures 1–4 present examples of pre-service chemistry teachers' drawings of complexometric titration.

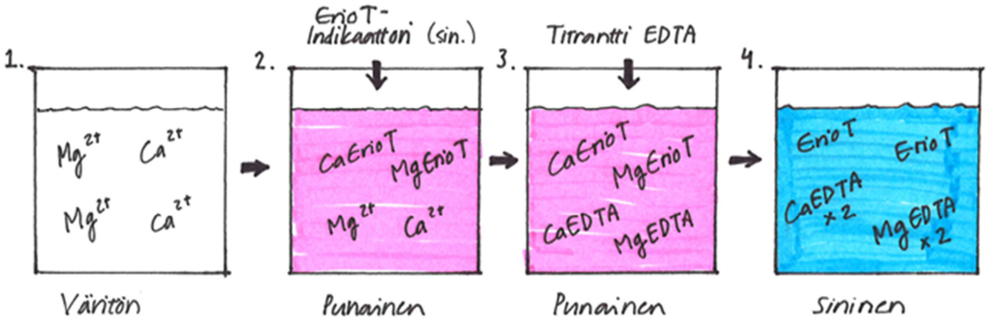

Figure 1. *Strip with four panels. The colors are written below the panels, and the solutions are also colored. Text in English: colorless, red, red, blue.*

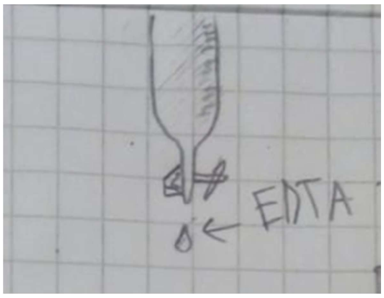

Figure 2. *Detail of drawing where the titrant is added: burette and drop of titrant (EDTA solution).*

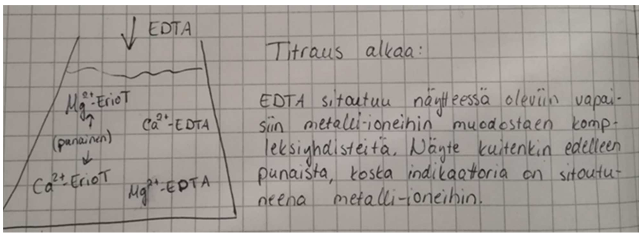

Figure 3. *Cartoon strip (phase: during titration), including a verbal description. Text in English: "Titration begins: EDTA binds to free metal ions of the sample, forming complex compounds. The color of the sample is still red, because the indicator binds to metal ions."*

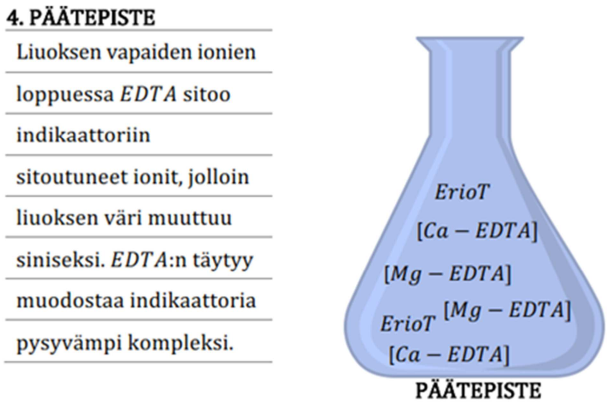

Figure 4. *Cartoon strip (phase: the endpoint of titration), including a verbal description. Text in English: "4. The endpoint. Once all the free ions of the solution react, EDTA binds ions which were earlier bound to the indicator, and the color of the solution changes to blue. EDTA forms a more stable complex than the indicator."*

4.4. Interview with Course Instructors

Three course instructors were also interviewed. All the instructors worked as teachers in chemistry education. Instructors' experience in the course varied from one year to 17 years. The sizes of teaching groups in the course are maximum 10 students, so instructors reported that they also have time to discuss the idea of experiments with each student or working pair. Classes have conversations about the pedagogical views of laboratory experiments.

According to the instructors, chemistry major students have performed titration experiments several times during their university studies, but chemistry minors typically have little experience. Some of the chemistry minors have relatively weak skills and knowledge in chemistry. For some students it is challenging that in titrations the practical procedure is typically the same, but the reactions and theory differ. Students can perform the titration experiment and do the calculations, but some of them have problems understanding which reactions occur in an Erlenmeyer flask, and what causes the change of color at the endpoint.

Instructors commented that teaching about titration demands discussions with students. A typical working method is that students first draw their strips and have a discussion with the instructor. In a way, students then acquire permission to start the experiment. For the instructor, checking the strip is an easy way to ensure that the student has understood the theory. Thus, a teacher can see the possible misconceptions held by students and address those.

Drawing cartoon strips as a tool to understand titration was a new method for the students. By drawing, students reviewed the phases and theory of titration. It was easy to divide titration into phases using cartoon strips. Instructors reported that it was easy to explain reactions during titration using cartoon strips. Moreover, cartoons strips bring together observations at the macroscopic level, and explanations at the submicroscopic and symbolic levels. The instructors felt the method to be positive, valuable and useful:

"*In my opinion, drawing cartoon strips is an excellent way to learn the theory of titration.*" (Instructor A)

At first, with acid-base-titration, students did not necessarily see drawing of cartoon strips to be useful. Later, as the theory became more complicated, such as with complexometric titration, the benefits of cartoon strips were unanimously accepted. Feedback from students was positive: they felt the method to be meaningful. According to instructor B, some students reported that after drawing the cartoon strips they really understood the theory of titration:

"*...students have sometimes comments like 'Why hasn't anybody told me this earlier! Only now do I really understand this!'*" (Instructor B)

In addition, pre-service chemistry teachers see the method as a pedagogic tool as a teacher. The instructors' opinion was that drawing cartoon strips was at that moment more like a tool for students' understanding. There are various ways to draw the cartoon strip, and students' output differ significantly from each other. Instructors pondered that in the future the focus could be more on the tidy appearance and pedagogical value of students' cartoon strips.

5. Conclusions

Pre-service chemistry teachers' found the visualization of titration using cartoon strips to be motivating and positive. The method was unanimously accepted and most of the students considered it to be enjoyable. Students viewed the method as a new experience: it was a new learning method and way to consider titration. Clearly, students felt that it helped them to understand titration better. Moreover, pre-service chemistry teachers saw that the used method would benefit their work as a teacher in the future.

According to the pre-service chemistry teachers, the method helped them to process titration more deeply, and to understand in more details its idea, theory, and phases. Students described that they understood the function and role of the indicator better and more precisely. According to earlier research results drawing pictures can develop a deeper understand of chemical phenomena [2, 8]. Students were also able to transfer their knowledge to new titration theories [5]. Moreover, the use of chemistry knowledge on multiple levels in visualizations leads to deeper learning [2]. Thus, the method used in this study was found to be a motivating learning tool which was accepted by the pre-service chemistry teachers, both for their own learning and as a possible tool for their own future teaching activities.

A working hypothesis here was that visual–verbal and visual–nonverbal students would benefit the most from the used method. The results of this research did not support this hypothesis. However, students who reported constructive learning theory to be closest to their own learning approach gave slightly more positive feedback on drawing cartoon strips.

In this research, based on the output of pre-service chemistry teachers and course instructors, the qualities and properties for a clear and pedagogically useful cartoon strip on titration were formulated. According to the course instructors, the focus in the future will be both on the correctness of the drawn cartoon strip, and on the revision of a pedagogically useful representation.

The course instructors reported that teachers' support is essential when pre-service chemistry teachers create their cartoon strips. Representations of challenging content may overload students' working memory [7] and thus discussion with the course instructor is necessary. Sometimes reading students' drawings can be challenging and demands explanations to be given by the students [2]. The arrangement that students first draw the cartoon strips and then the instructor discusses it with them has been demonstrated to be a successful and workable solution. The drawing of cartoon strips is also a tool for an instructor to evaluate learners' submicroscopic-level understanding, and to correct misconceptions [15]. A correct cartoon strip concerning titration can be used as an authorization to begin laboratory work.

When pre-service chemistry teachers are guided to draw their cartoon strip representations of titration, instructions must include a request to ponder all the phases and meanings of all the reagents. The instructor has to balance between giving strict instructions and models, and giving students the opportunity to construct their own creative, even playful models and thus develop their mental models [3, 14].

Just as classroom discussion offers possibilities for students to challenge, criticize and consider the science content being discussed [16], constructing students' own representations by drawing cartoon strips can achieve the same result. Cooperation and discussion with other students and the teacher helps students in this creative process.

In this study, visualizations created by pre-service chemistry education students themselves clearly helped students to deepen their understanding of the titration. Students felt that drawing cartoon strips was an effective and easily recoverable learning tool when the theory of titration was discussed. Moreover, students were able to adopt their knowledge when the theory of new type of titration was processed. Pre-service students were trained to draw scientific cartoon strips and to use those in learning of chemistry. Students expressed their will to use it as a chemistry teacher. Thus, the method proved to be suitable and applicable for learning and teaching purposes in chemistry teacher education.

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