

Design thinking in the development of stop-motion animations produced by future chemistry teachers

ABSTRACT

This work aims to present and discuss the use of the Design Thinking (DT) methodological approach in creating stop-motion animations by Chemistry undergraduate students at a Federal University. The Design Thinking teaching methodology has five stages: discovery, interpretation, ideation, experimentation, and evolution (IDEO, 2012). Guided by this approach, the objectives of this research consist of discussing the stages of Design Thinking in the elaboration of stop-motion animations and highlighting the contributions of DT to the development of the activity carried out. The research was conducted with ten students in the 5th semester of the Chemistry teaching degree who were doing the Supervised Internship course. To assess the use of the DT approach in developing the animation, the students received a questionnaire through which it was possible to analyze their opinions on the strengths and limitations of DT. The results show that the students acknowledge the possibilities of applying this methodology, mainly when associated with the fact that this is a process that can facilitate group work, make classes more lively, instigate curiosity, awaken students' interest in solving problems and challenges, and help learners to become active agents in the construction of their knowledge.

KEYWORDS: Chemistry education; Initial training; Methodologies; Information and Communication Technologies (ICTs).

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Design thinking na elaboração de animações stop motion produzidas por futuros professores de química

RESUMO

O presente trabalho tem como objetivo apresentar e discutir a utilização da abordagem metodológica Design Thinking (DT) na preparação de animações stop motion construídas por licenciandos em química de uma universidade federal. A metodologia de ensino Design Thinking divide-se em cinco etapas, a saber: descoberta, interpretação, ideação, experimentação e evolução (IDEO, 2012). Embasados nessa abordagem, os objetivos desta pesquisa consistem em: discutir as etapas do Design Thinking na elaboração de stop motion e evidenciar as contribuições do DT no desenvolvimento da atividade realizada. A pesquisa foi desenvolvida com dez licenciandos do 5º período do curso de Licenciatura em Química que cursavam a disciplina de Estágio Supervisionado. Para avaliar o uso da abordagem DT no processo de elaboração da animação, os licenciandos receberam um questionário no qual foi possível analisar a opinião deles quanto às potencialidades e limitações do Design Thinking. Nos resultados, mostramos que os licenciandos reconhecem as possibilidades do emprego da metodologia, associadas ao fato de ser um processo que pode facilitar o trabalho em grupo, dinamizar as aulas, instigar a curiosidade, despertar o interesse dos estudantes na resolução de problemas e desafios e contribuir para que os aprendizes se tornem sujeitos ativos na construção do seu próprio conhecimento.

PALAVRAS-CHAVE: Ensino de química; Formação inicial; Metodologias; Tecnologias de Informação e Comunicação (TICS).

INTRODUCTION

Students often see Chemistry lessons as demotivating since traditional teaching activities do not significantly contribute to learning scientific concepts (Pozo; Crespo, 2009). In order to change this scenario, it is necessary to look for new teaching methods, new alternatives, innovative resources, and the use of different information and communication technologies (ICTs) that enable students to learn dynamically and collaboratively. However, despite official documents and research in science teaching highlighting the importance of using ICTs in teaching practices, there are still insufficient initiatives to implement them in school environments (Rezende, 2000; Giordan, 2008; Morán, 2015).

In a survey carried out by Stanzani (2018), the researcher highlights the growing concern of researchers in the field to discuss the implementation of "specific disciplines in undergraduate courses to generate knowledge and enhance learning autonomy through the technological fluency necessary for the use of ICTs" (p. 30). In addition, the author points out the importance of equipping future teachers "so that they can use these technological resources in their professional practice, making the teaching and learning process more meaningful" (p. 30).

In this way, various studies have presented and discussed the possibilities of integrating ICTs into teaching and learning processes at different levels of education (Ponte, 2000; Brito, 2006; Morán, 2015; Santos et al., 2018). In chemistry teaching, specifically, there are various applications, such as virtual games, simulations, animations, and hypermedia, among other technological resources, which allow visualization of the representation of the submicroscopic field and a better understanding of chemical phenomena at the molecular, atomic level (Nichele; Schlemmer, 2014; Ramos et al., 2017). In this context, using animations such as stop motion can be an ally in understanding chemical content, which is often difficult to grasp because these concepts require a greater capacity for abstraction to be understood (Gibin, 2009).

Stop motion animation is a simple, low-cost filming technique that achieves very satisfactory results in terms of student interest in the animation. Due to the cheapening of digital equipment, such as camcorders and cell phone cameras, and with the emergence of applications and social networks that easily allow the creation of films, this technique has emerged as a possibility to provide greater playfulness, motivate the learning of chemical concepts, stimulate students' curiosity and imagination (Kaminski, 2010; Bossler, 2010).

Given this, initial training courses for chemistry teachers should provide undergraduates with theoretical foundations aimed at a better approach to scientific concepts through the use and discussion of different methodological strategies and resources to pique students' interest in the subject of chemistry in an attempt to overcome the limits imposed by the traditional teaching system. Based on the above, the work is based on the following problem: How can using the DT approach help undergraduates produce stop-motion animations for teaching chemistry? This research aims to present and discuss the stages of the Design Thinking (DT) approach in the production of stop motion animations and highlight the contributions of DT in developing the activity carried out in the training of future teachers.

THE DESIGN THINKING APPROACH IN THE SCHOOL CONTEXT

From the perspective of constructivist approaches, Design Thinking (DT) presents itself as a potential for new teaching and learning practices, as it places the student as the builder of their knowledge, values cooperative learning, the use of imagination and creativity in solving problems in the most varied contexts (IDEO, 2012; Brown, 2018). Therefore, the DT approach is one of the most relevant active methodologies for promoting student engagement and autonomy in solving the proposed challenge and can be used in education at different levels (Cavalcanti; Filatro, 2016; Leite, 2018; Silva Neto; Leite, 2020; Nascimento; Leite, 2021).

The American design and innovation company IDEO, in partnership with Ormondale Elementary and School (IDEO, 2012), popularized DT for educators. In 2013, the Educadigital Institute translated and adapted this methodology for educational scenarios and, in 2014, launched the Design Thinking for Educators material, available in chapters and activity books under the Creative Commons license (Instituto Educadigital, 2014).

DT should be guided by a theoretical or experimental challenge students must solve. This challenge must be clear and well-structured so that learners continue to the subsequent phases of the DT and become interested in seeking solutions to the proposed challenge (Instituto Educadigital, 2014; Martins-Filho; Gerges; Fialho, 2015; Zilli, 2015). In the educational context, the phases of DT are subdivided into (1) discovery, (2) interpretation, (3) ideation, (4) experimentation, and (5) evolution (IDEO, 2012). Each of these is explained in detail below.

1. Discovery: Students must understand the challenge set by the teacher and search for the information needed to find possible ways to solve the problem;
2. Interpretation: All the ideas discussed in the previous phase must be expressed using visual resources such as drawings, graphs, diagrams, flowcharts, mind maps, and different types of notes. Understanding the challenge and problem presented in the previous stage defines what should be done in this phase, which involves recording thoughts and observations to discuss the objective of the activity;
3. Ideation: Two actions must take place at this stage. Firstly, brainstorming must be carried out. Brainstorming is an English expression that means "brainstorming." At this stage, the students should share ideas about creating, elaborating, or solving the problem. After brainstorming, the second action consists of refining the ideas and choosing the most viable one to represent the proposed solution;
4. Experimentation: involves building prototypes such as a storyboard, diagram, advertisement, model, mock-up, staging, and creation of digital materials. The main objective of this stage is to visually and physically model the most relevant ideas listed in the previous phase;
5. Evolution: characterized by evaluating the activities and revisiting the objectives set at the start of the challenge to analyze the results obtained and their impact.

The importance of using the DT approach in teaching is emphasized because it is an active methodology that enables the development of activities that stimulate student participation and creativity, improve their ability to work in teams, and put them in the other person's shoes. Through it, traditional teaching practices are transformed into activities that prepare students for the knowledge society, collaborating directly with learning and social development, as well as contributing to the formation of a society that works for the benefit of the collective, in which everyone learns and respects each other's differences (Stumm; Wagner, 2019).

In recent years, various studies in a wide range of areas, such as IT, business administration, and education, among others, have sought to emphasize the potential of using DT in specific processes. However, teachers and researchers still have not explored the science teaching methodology. In searches carried out in 2020 in the theses and dissertations database of the Brazilian Institute of Information on Science and Technology (IBICT) and the Coordination for the Improvement of Higher Education Personnel (CAPES), we found only three studies on DT in science teaching. Of these, only one dissertation directly relates the use of DT to proposals for science teaching (Araújo, 2019), as shown in Table 1. The searches used the triggers "science teaching" and "design thinking." Titles, keywords, and abstracts were read from the results to filter out possible incoherent results.

Table 1

Description of research in Science Teaching using DT

Year of Publication	Reference	Use of DT
2019	Farias, M. S. F. de. (2019). <i>Design Thinking na elaboração de um produto educacional: roteiro de aprendizagem, estruturação e orientações</i> . [Dissertação de Mestrado]. Instituto Federal de Educação, Ciência e Tecnologia do Amazonas.	The author seeks to develop a learning script structure and guidelines for teachers' application of DT in their teaching context. In addition to carrying out cycles of application of the proposals for EJA (Youth and Adult Education) students, the author proposes workshops for physics, chemistry, biology, and mathematics undergraduates, seeking to discuss the construction of learning scripts.
2019	Araújo, T. V. L. de. (2019). <i>Implementação de um makerspace em séries iniciais do ensino fundamental</i> . [Dissertação de Mestrado]. Universidade Tecnológica Federal do Paraná.	The author proposes the development of a Maker Learning environment in the early years through DT, proposing a STEM (science, technology, engineering, and mathematics) instructional approach. The pilot project was tested in the municipal school system. As a result, a manual for implementing the proposal was

Year of Publication	Reference	Use of DT
		published and structured around the stages of the DT methodology.
2018	Britto, R. M. G. M. de. (2018). <i>Contribuições do design thinking para a formação docente: planejamento de atividade de ensino e aprendizagem</i> . [Tese de Doutorado]. Universidade Federal Rural de Pernambuco.	Seeking to answer the following research question: "Can teachers act as designers in the process of planning teaching and learning sequences based on the principles and tools of the DT approach?" the author proposes the realization of training moments methodologically oriented by DT in order to provide practicing teachers with new ways of acting in planning solutions to educational challenges.

Source: Authors (2023).

The authors of the works presented highlight the fact that DT has been shown to mobilize teachers to change their attitudes since the stages of DT do not present ready-made alternatives but instead propose that the teachers themselves be able to identify problems, map the context - which involves gathering reference data, identifying the characteristics of the target audience and delimiting the scope of the problem - and promote customized solutions for their environment, aiming for a new approach to existing conflicts or difficulties. In this way, the authors agree that DT allows the transition from selective and conservative practices to innovative ones by enhancing the exchange and generation of new ideas, awakening those involved to a collaborative culture (Britto, 2018; Farias, 2019; Araújo, 2019). In addition, skills such as empathy, creativity, and integrative thinking to solve a problem can improve the learning process of a student protagonist, just as they can help teaching practice (Silva Neto; Leite, 2020).

Nascimento and Leite (2021) carried out a systematic literature review of publications between 2010 and 2020, focusing on the objectives and applications of DT in Natural Sciences. Within the scope adopted, the authors also found few studies on the subject:

We also observed that the design thinking methodology is a good alternative for the classroom but still needs to be used. DT proposals need to be more usable, especially in teaching natural sciences. As observed in this research, only six papers involved teaching natural sciences with DT. This is why it is essential to make discussions about this methodology viable so that it can be incorporated into teaching and learning processes (Nascimento; Leite, 2021, pp. 26-27).

According to the authors above, DT can be applied in three ways: innovation approach, teaching and learning strategy, and methodological approach to problem-solving. In particular, in this research, we used DT as a methodology to guide the construction of stop motions to teach chemistry.

METHODOLOGICAL GUIDELINES

The methodology of this research takes a qualitative approach. In this type of research, the researcher's reflection is essential for collecting and discussing the data (Flick, 2009). Qualitative research requires investigation, interpretation, and understanding beyond simple discovery. Planning activities are essential in this process. Data collection follows an intuitive process (Ludke; André, 2014).

The research was conducted with ten fifth-year chemistry undergraduates enrolled in a supervised internship course at a federal university north of Paraná. The students, randomly coded from L1 to L10, formed two groups of four and one pair. In order to make it easier to read the data analysis and the relationship between the undergraduates and their respective groups, we have adopted identification codes, as shown in the following example: L5_2 (L5 refers to the student and the following number (2) indicates the group and the stop motion developed, in this case, SM2).

The Supervised Internship course has a timetable of five lessons per week, so the activities described here were carried out in one day, totaling five lessons of 50 minutes each. One of the subject's proposals discusses incorporating active methodologies and ICT into teaching chemistry in primary education. For this reason, the teacher in charge chose to work with the creation of Stop Motion animation, linked to the use of DT as a methodological approach. The undergraduates were, therefore, asked to create a stop-motion animation illustrating a chemical phenomenon, using the stages of DT as the methodology for this creation. The content was selected freely by the groups.

Given the scenario presented, before we explain in more depth how the DT methodology was implemented in our research, we will now consider how to create stop-motion animations.

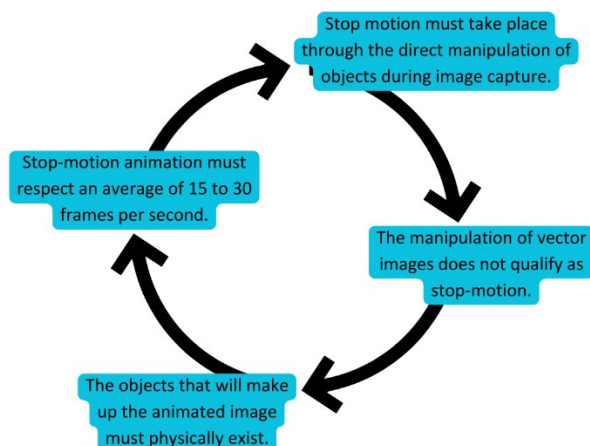
HOW TO CREATE A STOP MOTION

The stop motion technique is a type of animation widely used in cinemas and was developed by Englishman James Stuart Blackton in mid-1897. This animation technique involves sequencing different photographs of the same object to simulate the desired movement. The photographs are called frames and should generally be taken from a fixed point, with the object moving slightly. Stop motion is a simple animation technique that explains a concept or tells a story (Hoban; Nielsen, 2014).

Leite (2020) presents some characteristics that should be observed when making a stop motion, as shown in Figure 1. According to the author, the development of stop motion in the classroom contributes to the construction of chemical knowledge. According to the author, "Although the production of stop motion is not so common among young people, they consume and even produce videos of other various contents, so why not change the situation and propose that students produce their educational content?" (p. 15).

Figure 1

Characteristics of a stop-motion



Source: Adapted and translated from Leite (2020).

We present the main steps for creating a stop motion in Table 2 and the guidelines listed by Shaw (2013).

Table 2

Steps to create stop-motion

-
- 1º) Choose the camera and the objects to be animated. Cell phone cameras can be used;
 - 2º) Set the time the animation will take;
 - 3º) Prepare a setting with adequate lighting;
 - 4º) Try to leave the camera at a fixed point to shoot;
 - 5º) Create a script based on a specific theme or content;
 - 6º) Write the photo captions on paper, record the lines (like a narrated animation), or choose a soundtrack. The explanation can be enhanced with text or music;
 - 7º) Photograph the sequences of images you want to obtain;
 - 8º) Download the photos to your computer or cell phone so that you can edit the video using a primary application to generate the animations.
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Source: Adapted from Shaw (2013).

So, considering the 8th stage for creating stop-motion, as Shaw (2013) proposed, Table 3 below presents a list of some video editing applications that can be used to create stop-motion animation.

Table 3

Some applications that can be used in stop-motion creation

Operating System	Application
Android	PicPac; Motion-Stop Motion Camera, Estúdio Stop Motion
iOS	GorillaCam, Estúdio Stop Motion
Windows	MonkeyJam, AnimatorHD
MacOS	Sony Vegas Pro, iStopMotion, Take5

Source: Authors (2023).

The Stop Motion Studio Pro application, a free version available on the Play Store and Apple Store, was used to create the animations analyzed here. The application was suggested during a lecture introducing the stop motion animation technique, which is part of the actions planned in one of the stages of the DT approach described below.

DESIGN THINKING METHODOLOGICAL APPROACH IN THE CREATION OF STOP-MOTION ANIMATIONS

The challenge proposed to the undergraduates was: "Create a stop motion animation that can help primary school students understand chemical concepts." For a better understanding of the organization of the phases of the DT methodological approach, Table 4 describes the activities carried out in each stage of the methodology, according to IDEO (2012).

Table 4

Activities and estimated time for the DT phases

DT Stages	Main Steps	Description of activities	Duration of activities
1. Discovery	1.1 Understanding the challenge	A speaker was invited to explain the stop-motion animation technique.	30 min
	1.2 Preparing the research	The students chose the chemical content covered in the animation.	15 min
2. Interpretation	2.1 Finding the Objectives	The students defined the objective(s) of the animation.	15 min
3. Ideation	3.1 Generating ideas	This was the pre-production of the project. The students chose the materials used to make the stop motion and	40 min
	3.2 Refining		

DT Stages	Main Steps	Description of activities	Duration of activities
	ideas	planned the actions that would be carried out in the animation. The students were asked to draw up a storyboard.	
4. Experimentation	4.1 Making prototypes 4.2 Getting answers	It consisted of editing, filming, and digitally editing the stop-motion.	2h
5. Evolution	5.1 Evaluating the results 5.2 Implement	The students analyzed the process of creating the stop motion and suggested improvements.	20 min

Source: Authors (2023).

All the activities were carried out in teams to share and discuss ideas. In the last stage, to evaluate the use of DT in the creation of the stop motion, the undergraduates were given a questionnaire consisting of two questions, presented below:

Question 1: Which components of design thinking (discovery, interpretation, ideation, experimentation, and evolution) did you find most challenging to develop? Why? **Question 2:** Do you intend to use the Design Thinking approach on other occasions as a future teacher? Please comment on your answer.

Based on the answers to this questionnaire, we analyzed the opinions of future teachers regarding the potential and limitations of using the DT approach. Having presented the research context and guidelines, we now present the analysis and reflections on the data collected in all the proposal stages based on the stages of the DT approach.

RESULTS AND DISCUSSION

The animations produced by the students were developed as part of a Supervised Internship course in Chemistry. The future teachers learned how to make a stop motion using the DT approach as a methodology to help them construct the animation. These reflections aim to assess how the DT approach helped stop-motion development. In order to organize the presentation of the data, the discussion will be based on each of the stages of the DT approach.

STAGES 1 AND 2 - DISCOVERY AND INTERPRETATION

In the first stage, discovery, after the lecture and division into groups, the undergraduates chose the chemical concept represented in the stop motion. Then, they planned the video's objective in the interpretation stage, as shown in Table 5.

Table 5

Content and objective of the stop motion animations

Group Stop-Motion	Graduates	Concepts	Purpose of animation
SM1	L1, L2, L3 e L4	Physical states of matter	Facilitate visualization of molecules' degree of agitation and cohesion in the different physical states of matter.
SM2	L5 e L6	SN2 reaction	To help students understand the mechanism of SN2 reactions (nucleophilic substitution), a concept in Organic Chemistry, to enable 3D visualization of nucleophilic attack.
SM3	L7, L8, L9 e L10	pH indicator	Demonstrate the variation in color of solutions with differences in acidity and basicity using the bromothymol blue indicator.

Source: Authors (2023).

SM1 relates to the three states of aggregation of matter: solid, liquid, and gas and the change of physical state. Understanding these concepts is necessary for learning other chemical content. Thus, understanding these concepts can help learning (Harrison; Treagust, 2002; Silva, 2008). In this sense, the animation produced by the undergraduates can help students understand that matter is made up of particles in constant movement, that there are empty spaces between the particles, that there is a cohesive force between them, and that in order for a substance to change its physical state, it needs to be supplied with energy (Silva, 2008).

In SM2, the concept refers to nucleophilic substitution reactions. In this type of reaction, according to Solomons and Fryhle (2012, p. 88), "a nucleophile, a

species with a pair of unshared electrons, reacts with an alkyl halide - called the substrate - by replacing the substituent halogen," thus "a substitution reaction takes place, and the substituent halogen, called the withdrawing group, moves away with a halide ion ."A nucleophile initiates the substitution reaction, called a nucleophilic substitution (SN) reaction, which can occur in SN1 and SN2 reactions. In SM2, the students represented the mechanism of an SN2-type reaction, bimolecular nucleophilic substitution. In this type of reaction, "it is necessary for the nucleophile to collide with the alkyl halide, breaking the carbon-halogen bonds to form a new bond between the nucleophile and the carbon at the same time" (Solomons; Fryhle, 2012, p. 89). Therefore, as the inversion of the configuration (R-S; cis-trans) between reactants and products is not easily visualized by the students, the aim of the stop motion SM2 was to demonstrate how the inversion of the configuration of a molecule - (R)-2-chlorobutane - occurs based on the mechanism of the SN2 substitution reaction.

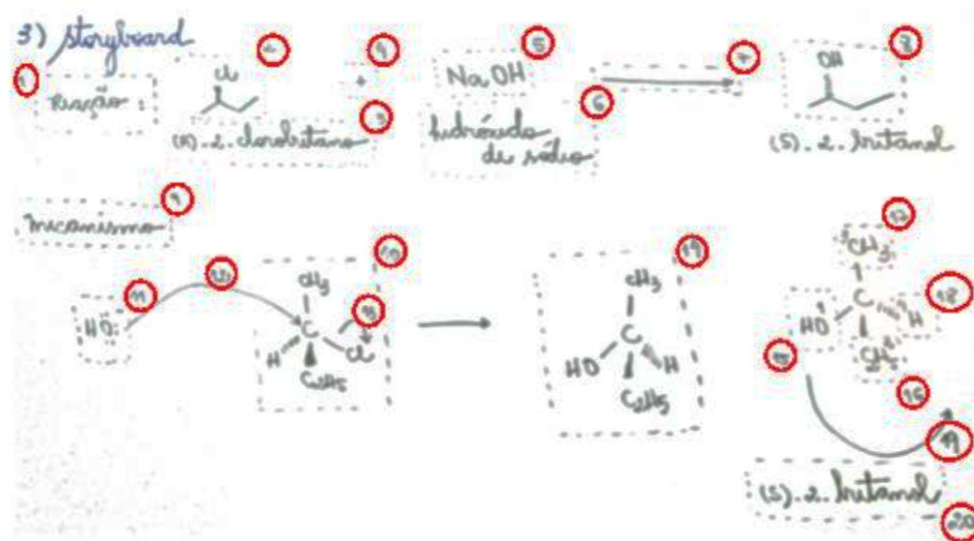
In SM3, the students chose the concept of acid-base indicators to build the stop motion. Acid-base indicators, or pH indicators, are weakly acidic or basic organic substances capable of changing color depending on pH (Baccan et al., 2001). The animation aimed to demonstrate the change in color of the indicator, bromothymol blue, according to the pH value of different solutions. At this stage, as well as defining the content to be worked on using stop motion, the undergraduates also defined the objectives. They organized their ideas so that, in the next stage, they could construct and analyze possible solutions to the proposed problem.

STAGE 3 - IDEATION

At this stage, the groups began to draw up the storyboards, as shown in the storyboard built by the SM2 undergraduates in Figure 2, in which the students organized all the movements, listed and highlighted in the red circles, that had to be carried out in order to achieve the objectives in the representation of the concept.

Figure 2

Storyboard produced by SM2 undergraduates



Source: Digitization of the storyboard built by SM2 undergraduates (2023).

As shown in Figure 2, the students are trying to demonstrate the inversion of the configuration by the SN2 reaction mechanism. For the reaction to occur, the hydroxide ion must attack carbon 2 of the substrate ((R)-2 chlorobutane) from the side opposite the C-Cl bond. As a result, the reaction occurs with an inversion of configuration, giving rise to a product with S stereochemistry ((S)-2-chlorobutane). This reaction is bimolecular, as two species are involved in the SN2-type reaction (Solomons; Fryhle, 2012).

The storyboards were very important in facilitating all the movements and actions to be photographed to produce the video. The numbers highlighted by the red circles in Figure 2 indicate what and how the images should be photographed, which made it easier for the students to develop the stop motion. They followed the guidelines indicated for this stage of the DT approach since the result presented in the storyboard shows the most viable idea defined by the group in order to solve the problem.

STAGE 4 - EXPERIMENTATION

At this stage, the undergraduates photographed the images for later video editing. Three stop-motion animations were obtained and made available on YouTube. The titles and links to the animations can be found in Chart 6.

Table 6

Stop-Motion produced by chemistry undergraduates

Stop Motion	Títulos	Links
SM1	Physical states of matter	https://youtu.be/YYTxPTa2f7I
SM2	SN2 reaction	https://youtu.be/i83T-tjSziI
SM3	pH indicator	https://youtu.be/GqqnhTVQHqQ

Source: Authors (2023).

In the SM1 animation, it was possible to observe the variation in the degree of agitation and the distance of the molecules when the system was heated, increasing successively from the solid state to the liquid state and from the liquid state to the gaseous state. Thus, for phase changes to occur, energy must be supplied, as demonstrated in the video.

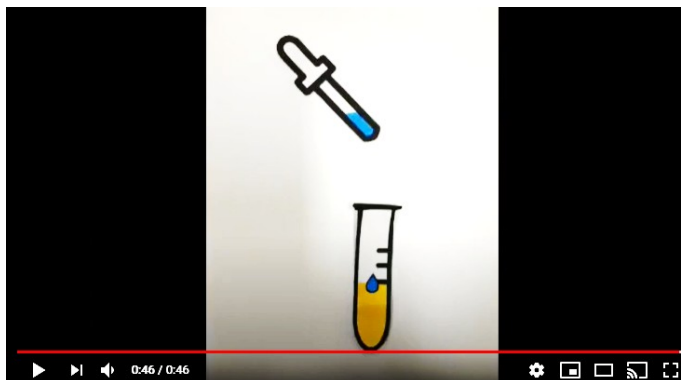
Some studies point to students' difficulties and alternative conceptions when interpreting the microscopic behavior of matter (Lesniak, 2005; Silva, 2008; Pozo; Crespo, 2009). For example, Silva (2008) investigated the persistence of inadequate conceptions held by students on a Chemistry degree course after they had studied General Chemistry related to the different states of aggregation of particles in the three states of matter, highlighting the importance of teachers using different teaching strategies, as well as the use of visual resources to facilitate the understanding of submicroscopic phenomena and minimize the alternative conceptions that students have about this concept.

The SM2 animation enables 3D visualization of nucleophilic attack/substitution in the (R)-2-chlorobutane molecule. Neto, Campos and Marcelino-Jr. (2013) points to a significant amount of research related to the difficulties of spatial visions that students at different levels of education encounter when approaching the mechanisms of organic reactions (Nascimento Silva; Neto; Silva, 2015). Due to the high degree of abstraction and need for spatial visualization, stop motion animations can help understand the concept since "it enables new ways of visualizing content from different angles and possibilities" (LEITE, 2020, p. 19).

About SM3, the undergraduates showed a color change in acidic and basic substances when using the bromothymol blue pH indicator. The indicator turns yellow in acidic solutions, as shown in Figure 3, green in neutral solutions, and blue in basic solutions, as shown in the animation. Although the experiments carried out with pH indicators are considered relatively simple, low cost, and involve the use of few reagents and materials (Terci; Rossi, 2002), the use of stop motion expands the possibilities of how this chemical concept can be worked on in a classroom and can be adapted according to the teacher's planning.

Figure 3

Printscreen of the SM3 video available on YouTube



Source: Authors (2023).

In this stage of the DT approach, the planning carried out in the previous stages was realized by managing the models and materials produced, which enabled the animations to be created.

STAGE 5 - EVOLUTION - EVALUATION OF THE DT APPROACH AND STOP MOTION ANIMATIONS

In order to evaluate the DT approach, the undergraduates answered two questions listed in the methodology individually. The difficulties encountered in the process of making the stop motion, using the DT approach as a guiding principle, were pointed out in the answers to Question 1 - *Which components of design thinking (discovery, interpretation, ideation, experimentation, and evolution) did you find most challenging to develop? Why?*

When analyzing the answers, three undergraduates, L7_3, L9_3, and L10_3, considered that the discovery stage was the most difficult, as indicated by their answers:

L7_3: *Discovery was the most challenging stage because initially, we were in doubt between two ideas, TLV (Valence Bond Theory) and the pH scale, but we preferred to make the animation about the pH scale because it was easier to make the stop motion.*

L9_3: *The discovery was the most complicated stage because you need to consider how to assemble the idea in your head. It was challenging to decide which theory we would represent between the TLV theory and acid and base.*

L10_3: *The discovery because it was challenging to think of a concept that would be cool to create.*

In the previous answers, the students in the SM3 group discussed the possible concepts that could be represented in the animation, such as Valence Bond Theory (VLT), acids and bases, or pH indicators, before converging on the concept that would be animated.

In this context, the trainees used adjectives such as "easy" and "cool" to justify their choice of concept to be represented in the animation and overcome an initial difficulty related to creating a stop motion for teaching a chemical concept. Thus, considering the guidelines for this specific stage of the DT, which proposes the identification of difficulties and barriers related to the topic, students must have the opportunity to discuss and share their doubts in order to solve the proposed problem since both the DT approach and the creation of a stop motion are new elements to be signified by future teachers. In this vein, Zilli (2015) stresses that the teacher must be attentive to the team's opinions and decisions to enrich the development process and help them with their activities.

Undergraduates L5_2, L6_2, L1_1, and L3_1 had difficulties in the ideation stage, as the following reports show:

L5_2: *For me, the main difficulty was structuring the setting for the photos in the ideation phase to make the concept intelligible to the viewer.*

L6_2: *My most significant difficulty was in the ideation stage because I carefully thought about how to sequence the stop-motion images.*

L1_1: *The ideation stage was the most trying stage because I had to draw the images, but I did much thinking to photograph the pictures more calmly.*

L3_1: *The most significant difficulty was creativity because we had to translate the idea into a project that was easy for the students to understand.*

It was noted from the students' writing that the difficulties they faced at this stage were mainly related to two aspects: the construction of the scenarios/images and how to facilitate the students' understanding of the concepts. It is evident here that the undergraduates, when reflecting on the materialization of the planning, sought to relate the phases of creation, elaboration, and resolution of the problem, considering essential elements for the construction of the storyboard, the discussion/representation of chemical concepts from the sequence of images, in order to contemplate the objectives initially set.

In addition, we can say that this space for reflection and learning was necessary for future teachers to externalize concepts learned in other specific disciplines of the course because "learning a scientific concept is learning to talk about that concept, using the meaning accepted by the scientific community and society in which we are inserted" (NASCIMENTO SILVA; NETO; SILVA, 2015, p. 39).

Undergraduates L2_1, L4_1, and L8_3 had difficulties at the experimentation stage, as the following reports show:

L2_1: *The main difficulty was experimentation, i.e., doing the whole stop-motion process.*

L4_1: *In the experimentation part, we had some problems with correctly sequencing the photos.*

L8_3: *The most challenging part was experimenting, taking photos, and editing the video in the app.*

It is worth pointing out that the undergraduates were making stop-motion animations for the first time, which is one of the reasons why the students needed help executing the ideas planned during the previous phases. However, they all reported that creating the stop motion was enjoyable and exciting.

The data collected through Question 2: *Do you intend to use the Design Thinking approach on other occasions as a future teacher?* Comment on your answer - regarding the potential of using this approach in the classroom; it showed that all the undergraduates indicated the possibility of using the approach, as reported by L2_1:

L2_1: *Yes. The DT methodology proved to be effective in constructing the stop motion. The stages of the DT helped develop the proposal since they guided the activities carried out.*

Another potentiality was associated with the fact that it is a tool that helps with group work, as L5_1 and L10_3 pointed out:

L5_1: *[...] The methodology is labor-intensive but requires teachers and students to work together, making it an activity that motivates learning.*

L10_3: *Yes, because students can work in groups more dynamically.*

Therefore, as the answers collected in this investigation indicate, the participants consider incorporating new practices into chemistry teaching relevant. The justifications for the potential of using the DT approach were associated with the fact that it is a process that can facilitate group work in teaching and learning processes, contribute to the construction of scientific knowledge, make classes more dynamic, instigate curiosity, and stimulate students' interest in solving problems and challenges.

Still, about question 2, only L7_3 presented some obstacles to incorporating the proposal into his teaching practice.

L7_3: *I intend to, but I must plan a lot because it is much work.*

Using the DT approach in the classroom requires time to carry out the activity, and the teacher needs to be aware of the reasonable minimum time required for the strategy to be implemented satisfactorily. Teodoro, Cabral, and Queiroz (2015) also point out that when opting for cooperative strategies in teaching environments, teachers must be aware that their application requires much effort, especially in organizing and managing activities.

About the animations produced, the students analyzed the process of creating stop motion and made suggestions for improvement. All the undergraduates made suggestions regarding the number of frames used to create the animation.

L2_1: *One suggestion for our stop motion would be to make more frames.*

L6_2: *Perhaps we could have taken more pictures to make the nucleophile attack and the group's departure more pronounced because that part of the video was a bit rushed.*

The increase in the number of frames per second implies the quality of the animation; however, due to the short period needed to prepare the stop motion, the students could not shoot more images, which could have resulted in more complete and elaborate animations.

The stop motion animations analyzed here used approximately two frames to produce 1 second of film. The students were asked to develop an animation resulting in a video of between 20 and 50 seconds. Therefore, to produce a 20-second video, approximately 40 shots were needed. The number of frames can vary according to the intentions of the teacher and the students, but as Leite (2020) states, "the more frames used, the smoother the result of the video" (p. 14).

Finally, in general, the undergraduates agree that the DT approach provides students with a dynamic and cooperative learning environment, as does the creation of stop-motion animations.

FINAL CONSIDERATIONS

This research sought to present the process of making stop motion animations by future chemistry teachers using the DT approach to analyze the positive and negative aspects of using this approach in teaching practices. The components of the DT that the trainees found most challenging were the discovery, ideation, and experimentation stages.

In the first stage, the most significant difficulties were choosing the concept to be animated. In the ideation stage, the obstacles were related to drawing up the storyboards, and in the experimentation stage, the students reported their limitations in setting up and creating the animation. Despite this, the undergraduates recognized the potential of using this approach associated with the fact that it is a process that can facilitate group work, make classes more dynamic, instigate curiosity, arouse students' interest in solving problems and challenges, and help primary school students become active subjects in the construction of their knowledge.

Given the analysis carried out, the results were satisfactory. The students' involvement and motivation in carrying out the proposed activities were evident, as was their great interest in learning how to develop each of the stages of the DT approach while making the stop-motion animations.

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