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Constitution of creative action in Mathematical Modeling

Constituição da ação criativa em Modelagem Matemática

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Abstract

This paper presents aims at showing some results obtained from a qualitative research to understand how the creative action occurs in a group of academics of a Mathematics Course of a public university in western Paraná. They dealt with modeling activities in a Mathematical Modeling I subject. The selected group was recorded during the development of the activities. Excerpts were selected from the students' transcriptions that indicated creative action constitution. Then, there were findings and synthesis to build the studied categories. At last, according to the analysis of one category, we concluded that creative actions are formed by interventions and other elements that worked as initial triggers, creative triggers, or as inhibiting interventions.

Keywords: Mathematics Education; Cultural Psychology of Creativity; Creativity in teaching and learning processes.

Resumo

Este artigo apresenta parte dos resultados de uma pesquisa qualitativa que objetivou compreender como se constitui a ação criativa de um grupo de estudantes de um curso de Licenciatura em Matemática de uma universidade pública do oeste paranaense, ao lidar com atividades de Modelagem no contexto da disciplina de Modelagem Matemática I. A partir das transcrições de gravações de um grupo durante o desenvolvimento das atividades, selecionamos excertos que apresentavam indícios da constituição da ação criativa; em seguida, tecemos constatações e sínteses para a construção de categorias. Com base nas análises de uma das categorias, verificou-se que as ações criativas se constituem por intervenções e elementos que funcionam ora como gatilhos iniciais, ora como gatilhos de criação e ora como intervenções inibidoras.

Palavras-chave: Educação Matemática; Psicologia Cultural da Criatividade; Criatividade nos processos de ensino e de aprendizagem.

Introduction

The concept of creativity has found application in diverse contexts such as business, culture, and education. It is usually associated with innovation and problem-solving, making

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it a crucial skill in the 21st century due to multifaceted challenges and dynamic developments. In Education field, particularly in recent times, efforts have been directed towards refining methodologies that facilitate creative attitudes, consequently creative individuals.

Alencar, Braga and Marinho (2016) pointed out that the ability to create thought can be widen up applying techniques, reinforcement of attitudes, behaviors, values, beliefs and personal attributes, which foster independent, flexible and imaginative thinking. Moreover, according to Pereira and Burak (2008, p. 6), "it can be affirmed that the environment, specially the classroom atmosphere and the teacher's behavior play an important role in students' creativity development, as well as in the creative process, which lead to a final a product".

Thus, we perceive that it is substantial for schools to provide classrooms and environments wherein students can develop creativity, exemplified by the Mathematical Modeling (MM) as a pedagogical practice (Schrenk & Vertuan, 2022). Mathematical Modeling is an environment where students are free to apply their skills that, although at first seem unrelated to mathematics, when engaged in learning and practicing mathematics, they open up creativity, including mathematical creativity.

Some scholars, including Pereira (2008), Brandt (2016) and Wessels (2014), have shown viewpoints regarding the relationship between Mathematical Modeling activities and the creativity development. However, there are still few studies dedicated to aspects related to the creative actions of individuals when developing Mathematical Modeling activities.

According to a core principles within the Cultural Psychology of Creativity approach (Glăveanu, 2014), creative actions externalize, express or generate a result that in outcomes imbued with materiality (object, process, model, strategy, experimentation...). They are "always, clearly, situational and/or contextual" (Glăveanu & Neves-Pereira, 2020, p. 143). In essence, the creative process is a form or quality of action, which is always influenced by a context.

Thus, based on the requirement presented in the literature, to contribute to the background of creative individuals, the possibility of fostering this creativity from the development of Modeling activities, and also scarcity of research committed to students' creative actions in this field, we developed this qualitative research to understand how one of the elements of research concerning creativity is constituted, since it belongs to the creative process, which is the creative action. In this case, undergraduating students of the Mathematics course from a public university in western Paraná dealt with modeling activities in the discipline of Mathematical Modeling I. So, this study aimed at answering the following research question: How are the creative actions of a group of undergraduating Mathematics students constituted when they deal with Mathematical Modeling activities?

Within this trial, a singular result comes out: that the creative actions of this group of students, when dealing with Mathematical Modeling activities, are constituted by interventions and elements. And these factors work sometimes as initial triggers, sometimes

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as triggers of creation and sometimes as inhibitory interventions.

Mathematical Modeling and Creativity

Mathematical Modeling, as a pedagogical practice (Schrenk & Vertuan, 2022), is a teaching methodology (Burak, 2004) or a pedagogical alternative (Almeida, Silva & Vertuan; 2013) that, from the perspective of Mathematics Education, has been gaining opportunities in classrooms lately. Research has highlighted its potential to develop several students' skills, including creativity (Pereira, 2008; Brandt, 2016; Wessels, 2014, among others).

The main feature of Modeling resides in its ability to impart a mathematical approach to a non-essentially mathematical problem situation (Almeida et al., 2013). As much, a Mathematical Modeling activity can be described in an initial situation (problematic), in a desired final situation (which represents a solution to the initial situation) and in a set of procedures and concepts essential to move from the initial situation to the last one (Almeida et al., 2013, p. 12).

When experiencing these procedures, which can be associated with some phases – integration, mathematization, resolution, interpretation of results and validation (Almeida et al., 2013) –, students undertake different cognitive actions that can be more or less intense, depending on activities and students (Almeida et al., 2013).

We also consider the process of developing a Modeling activity as a creative process and the actions that are undertaken as creative actions, as students need to produce solutions, referrals and strategies to resolve the situation, mainly within the group.

When Modeling researches mention Creativity, they usually do so with two main goals: either to state that the development of Modeling activities promotes students' creativity or because students are compelled to be creative to develop Modeling activities (Setti, Viana & Vertuan; 2019). But what kind of creativity is this and how can it be present in modeling activities? This is still an incipient discussion in the academy?

Among the research approaches in Creativity, some of them present a sociocultural understanding of creativity, such as Systems Theory, by Csikszentmihalyi; Vygotsky's Model of Creative Imagination and Glăveanu's Cultural Psychology of Creativity. We perceive that these approaches are congruent with the investigation of creativity in Education and, more specifically, in Mathematics teaching with Mathematical Modeling.

Vygotsky is widely acknowledged as the founder of sociocultural approaches on creativity, as he considers it be a phenomenon inherently shaped by cultural mediation. So, it arises through interactions among individuals who use signs and tools available in their surrounding context.

According to Neves-Pereira & Chagas-Ferreira (2020, p. 121), "Vygotsky and his collaborators assume that the superior mental functions of man, which includes creativity, come from the socio-historical stage, due to individuals' interactions and culture". Thus,

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according to the authors, creativity is the interaction between an individual and culture, provided by the lines of development and learning. According to this conception, creativity is assumed as a "superior psychological function, built based on the interactions between man and culture, mediated by other social elements, but with some characteristics of its own" (p.121).

Mihaly Csikszentmihalyi (1934 – 2021), a distinguished researcher and theorist of psychology, devoted a great part of his academic career to studies on creativity, and developed Systems Theory. The main characteristics of this model are the conception that each person is potentially creative and that creativity depends more on the social and cultural context than on the characteristics of the individual. Creativity transcends being an isolated result of individual actions, rather, it is the result of the interaction of three systems: individual (genetic background and personal experiences), domain (culture and scientific production) and field (social system) (Csikszentmihalyi, 1999). In essence, creativity is not only an internal cognition, but rather in the dynamic of sociocultural interaction.

Cultural Psychology of Creativity emerges when culture is considered a constituent element of creativity. Glăveanu (2010) has already stated that everyday expressions of creativity are what matters most for cultural psychology of creativity. Therefore, Glăveanu and Neves-Pereira (2020) highlight that creativity is conceptualized from a perspective of cultural psychology, and these authors draw attention to the fact that creativity is based on processes. So, it is required to think of creativity as the dynamic quality of our relationship with the environment, as something that arises from the "relation" among the individual (self), the others and culture. So, according to the authors,

> The cultural psychology of creativity, despite it still works with previously established notions of creativity (that is, production of significant innovations) shifts (1) the focus from products to processes (action), (2) from the individual to relationships (the individual and the world) and (3) from universal to contextual measures of creativity. The appraisal that something is "creative" remains relevant, even if everyone involved does not share this conception, or even if this evaluation changes over time (Glăveanu & Neves-Pereira, 2020, p. 153).

Within this context, "creating means acting in and on the world to generate significant news that can transform the person who creates them and their context so that they are appreciated as creative by those involved" (Glăveanu & Neves-Pereira, 2020, p 152).

Methodological Referrals

Data collection took place from March to December, 2020, in a Mathematical Modeling I discipline, offered as a part of a Mathematics undergraduate Course at a public university in western Paraná. There were 19 students in the class, who were studying the 7th period of the Bachelor's Degree.

As we glimpsed understanding students' creative action when dealing with Modeling activities, during the activities, we decided to elect one of the five groups to carry out the

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analyses, which allowed for a more attentive and thorough analysis. Thus, we studied as research *corpus* the production, actions and sayings of the members of the chosen group, composed of five students. The face-to-face classes were recorded in audio and video and the other virtual classes happened online due to the lockdown caused by the Sars-Cov-2 pandemic, so, they were recorded on the Google Meet platform. The moments of group discussion, however, were carried out on Skype platform. This last platform was chosen due to it allows teachers to be able to visit all groups in the same class, so that all discussions were recorded, as well as the conversations could be carried out in the chat, regardless of whether the meetings took place during class time or at extra-class times.

The course discipline usually covered the preparation of Modeling problems, as well as the development and socialization of modeling activities publicized in literature on creating Modeling activities, during some discussions with research professors on Modeling, reading and thinking about texts on Modeling in the classroom.

For data analysis, we heard recordings of all classes and the moments when the group members met, coded in alphabetical order as S1 for student 1, S2 for student 2 and so on. In addition to the regent professor (PR), the researcher Res.1 and her advisor (AD) and another researcher from the same graduating program (Res.2) participated as invited professors of the discipline. Also, when there were interventions by students from other groups, these were coded as EA. The recordings were revisited a few times and the moments of interaction among the group members, as well as between the group and the class were transcribed in full.

In this paper, we chose to consider moments experienced by students in different Mathematical Modeling activities, developed throughout the discipline, instead of taking one or the other as representative. Thus, we present, in footnotes, the idea of activity undertaken by the class the first time it is mentioned to minimally contextualize the reader about the activities.

Data analysis method was inspired by Setti, Waideman and Vertuan (2021), in which the authors establish four steps, as: 1. *Corpus* acknowledgement; 2. Internalization; 3. *Corpus* interpretation, and 4. Analysis of the Elaboration Path Scheme. However, for this research, we adapted the steps according to the investigation requirement (Chart 1).

Chart 1- Steps of the analysis method

STEPS	SUBSTEPS
1. *Corpus recognition*	1.1 Revisiting the recordings
	1.2 Dialogues transcription of the group
	1.3 Previous reading of transcripts
2. Internalization	2.1 *rereading of the corpus* [several times]
	2.2 Highlight of findings
3 *corpus interpretation*	3.1 Construction of Syntheses
4. Analysis of Creative Actions	4.1 Construction and analysis of categories

Source: Setti (2022).

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The *Corpus* Recognition step was carried out by revisiting recordings of all the meetings with class and meetings of the selected group, transcription of the group's dialogues and previous reading of those transcripts. The transcripts were organized according to each activity that the group developed, in chronological order, coded as A1 to transcript the first activity developed and so on.

The Internalization step of the actions undertaken by students in the group context was carried out by re-reading (several times) the dialogues transcription and revisiting the recordings, when necessary. During Internalization, it was important to infer about the students' cognitive processes, giving emphasis on the moments in which there was manifestation of actions that contributed with the creative process, which are called findings. After the internalization process, there was the *Corpus* Interpretation step, which consisted of interpreting the established findings, thus, the syntheses of the actions were built based on the group results. Syntheses correspond to an interpretation of a finding based on the research question, and constitute an analytical movement of the obtained data. Besides, the charts below will also present excerpts (Ex.) of the participants' dialogues.

Then, the syntheses were separated into groups in an electronic spreadsheet according to their similarities and, finally, organized the groupings into categories. The description of each category was carried out based on excerpts, findings and syntheses. Thus, we undertook the data analysis movement in the light of the established theoretical framework.

Here, the analyses are shown into one of the constitutive categories of this research, that is, the one that discusses that creative actions are constituted by interventions and elements that sometimes work as creation triggers and sometimes as inhibiting interventions.

Constitution of creative actions in Mathematical Modeling

The dialogues established within the investigated group, as well as the students' speeches and even the professors' ones intervened and exercised different kinds of influences in relation to the effectiveness of the group's creative actions. Similarly, some elements in this process, such as the short time to develop the activities, lack of material resources, among others, also showed this characteristic of intervening in creative actions. Thus, when we questioned ourselves about the movements that triggered creative actions regarding the development of different Mathematical Modeling activities, we could observe a certain pattern in the interventions carried out either by teachers or by the students themselves, called **initial triggers**.

The initial triggers are the interventions that, intentionally or not, **provoked a movement to think about, discuss about something, takes a stand on an issue**. For example, when a member of the group asks, "how did you think of that?", in order to head other members to think and argue about this topic. Also, when a member of the group said, "there are many variables that influence this situation", it triggered a movement in the group to discuss which variables have influenced the investigated phenomenon and what was

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needed to consider. This discussion (or viewpoint) of the group, triggered by the triggering intervention, could produce an idea that students could invest in, an idea with the potential to trigger the resolution, or part of the problem solving. That is, the initial trigger sets the course of a creative action in motion and it is in this movement that ideas come.

Some of these **ideas** seemed to **trigger students' investment in resolution referrals** and, therefore, we called them **creation triggers**. This is the case when in Episode 1 (Chart 2 below), understanding the importance of the idea to elaborate a problem about "depression at the university", the students and the professor begin to talk about the topic. At that moment, situations related to it were questioned in order to problematize them, such as depression in children and anxiety caused by large-scale evaluations. The situations related to the theme that were expressed by the group members and by the teacher aroused a movement of thinking about the situation. These initial triggers led to professor's intervention to suggest that they could take advantage of the topic 'childhood depression', based on the statements made by the group itself, which showed interest and appreciation for this topic, to elaborate the Modeling problem, a task to which the students were dedicated at that time. This intervention was set up as a creation trigger, since, from it, the group proceeded with the creative action to prepare a Modeling problem, which is now more focused on one of the different ideas discussed by the group.

On the other hand, there are interventions that, although they seemed to deal with plausible ideas that, for some reason, discouraged students from investing in themselves, or interventions that invalidated some idea or action, which is why we called them **inhibiting interventions**. They took place throughout the development of a Modeling activity. Sometimes, however, when dealing with them, the students envisaged and headed other resolution strategies.

Chart 2 – Episode 1 [A1 – Depression at the university]

S1: *Actually, it's not only about suicide, it's about depression and anxiety at the university. We don't know what to ask.* **[they express their difficulty in establishing an adversity to elaborate the problem]** [...]. PR: *Yeah, actually, it's pretty common. Even if we stop to think about the children themselves nowadays, let's see how anxious they are*. **[comment configured as an INITIAL TRIGGER]** S1: Guys, my cousin felt sick on the day of the Paraná contest. Can you get this? She felt really sick. **[comment connected to the teacher's, in order to complement the speech about anxiety in children - INITIAL TRIGGER]** [...] PR: *now, let's think, Can you imagine which subjects can be discussed? What question could be made based on all these discussions that you had? Look, as we said ... ah, my sister went to a contest and she felt sick... and so on.... Could this idea you be used to ask a question?* **[CREATION TRIGGER – appreciation of speech and motivation to take advantage of it]** S2: *the problem is mathematics, right...* And... [**this statement can denote INHIBITORY for S2 who is concerned with the issue of mathematics. But, at the same time, it can be an INITIAL TRIGGER for the next speech by the professor who contributed to the elaboration of the problem**]. [...]

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PR: *but that's the question! Is it imperative to have math in the question? Think about the issue of toilet paper, what was it like?* [INITIAL TRIGGER - clarified the need for mathematics not to appear in the problem – to afford assurance]

S2 *But, the problem is to pose a question that does not support him to start a thought/ brainstorming. Like, they cause several deaths and so on, but it doesn't have a bias to stimulate some thought. That's the problem.* **[INHIBITOR – insecurity in formulating the problem so that it triggers an investigation]**
PR: *ok, think, what would be interesting to discuss in this situation for you, in this context?* **[INITIAL TRIGGER - mediation/questioning]**
S2: *or up from some age on, because from that age it starts to be...* [**CREATION TRIGGER - idea starting to be built]**
[A1.Ex1]

Source: Setti (2022) and translated to this paper.

The investment in an initial trigger or not, however, was clear along the students' work dynamics, so that characterizing them as initial triggers or inhibitory interventions, in this research, depended on how the students' group reacted to each one of them. That is, the characterization will depend on the group receptiveness, and on the moment during the students' discussion while dealing with the Modeling activity. In other words, an intervention may be an initial trigger for an individual and an inhibitory intervention for the other, or an initial trigger in one situation and an inhibitory intervention in another. For example, S2's speech in Episode 1 (Chart 2) - S2: *the problem is mathematics, right*... And ... – this may have denoted an inhibiting element for S2, who is concerned with the mathematical content, but, at the same time, it may have been configured as an initial trigger for the professor's speech that triggered the problem preparation – PR: *but that's the question! Is it imperative to have mathematics in a question? Think about the idea of toilet paper, what was it like*?

Interventions, sometimes as initial triggers, sometimes as creation triggers and sometimes as inhibitors, took place along the creative action, with different implications. However, none of the members thought "now I'm going to intervene and it will work as an initial trigger", or "I'm going to inhibit creative action", but, when manifesting, when discussing, some things worked as triggers or as inhibitors for creative actions.

We also observed that, from a cognitive viewpoint, creation triggers were mostly manifested, at least openly in the group, after one or more initial triggers. These were usually caused by a third person, whether a member of the group or even by the professor who, yearned to understand the student's thinking, the applied strategy or the idea expressed, asked questions that seemed to be initial triggers for the emergence of a creation trigger.

In this context, we observed that the creation triggers, from interventions by the students in the group, were preceded by initial triggers that arose both unpretentiously in the dialogue on topics that were not necessarily related to what was intended in the initial planning of the group, such as when S1 mentions a fact that happened to a family member in the activity related to depression at the university (Chart 3-A), as **unintentional initial triggers**; and they came to light intentionally, to understand the plan, to clarify a doubt, to suggest something or to mediate the situation, as when S3 suggests using a measuring cup for

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activity A4, which aimed to calculate the volume of an apple (Chart 3-B), the were **intentional triggers**.

Chart 3 – Episode 2 [A1– Depression at the university and A4 – Apple Volume]

A - S1: Guys, my cousin felt sick on the day of the Paraná contest. Can you get this? She felt really sick **[A1.Ex7]**
B - *S3: Another thing, you said something about cutting, yeah. We have these milliliter cups here at home, so I don't know if we can do anything with them.* **[A4.Ex14]**

Source: Setti (2022) and translated to this paper.

There were initial triggers that also worked as creation triggers (Chart 4-A), such as when the individual says to the other, "*listen, but what if we do 'this'*?". This intervention is both an initial trigger and a creation trigger. Or even they are inhibitors (Chart 4-B), for example, when someone says, "[...] *it is not relevant, we don't use it*".

Chart 4 – Episode 3 [A5– Potato plantation [3]]

A - *S4: and if you were to take the total number of potatoes you'll need it in a bushel and divide it by the total square meters, to know how many potatoes you need in each square meter, would that help?* **[A5/.Ex15]**
S5: [...] *Wouldn't it have to be between 40 and 45, the rows? Or not necessarily*? EA: *No. That 45, it's not relevant, so we almost don't use it.* [**A5.Ex4**]

Source: Setti (2022) and translated to this paper.

Furthermore, it is important to explain that we understand that interventions do not necessarily follow a binary logic, such as "it is either a provocative trigger or an inhibitor", but that they can be compared to a segment, as the one represented in Figure 1, which denotes the intensity of interventions, so that they can be either more provocative (red end) or more inhibiting (blue end).

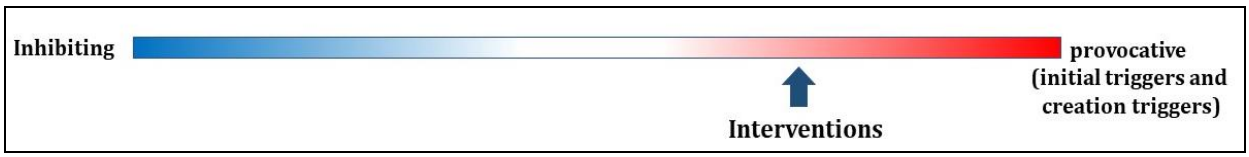

Figure 1 - Scheme Inhibiting and provocative interventions
Source: Setti (2022) and translated to this paper.

When it is considering this *continuum* between the most inhibiting and the most provocative intervention, a neutrality zone was built up, represented by the white color in the figure above. We understand that this zone of neutrality represents interventions that did not work either as inhibitors, or as initial triggers, or as creation triggers. They are part of the path that solves Mathematical Modeling problem, but they did not interfere significantly in the creative action. They can be random statements by the group members or the teacher, or even statements that even represented some intention to trigger, which were ignored or not legitimized by the other group members.

[3] This activity consists of investigating the optimal distance between potatoes cropped on a rural property, so that production can be maximum (Bassanezi, 2002).

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Identifying the initial triggers and differentiating them from the creation triggers, or from the inhibiting interventions during the group dialogue, was not an easy task, but, for our research, they became necessary to understand how the interventions influenced the creative action, bearing in mind that we understand that it is possible to infer how the dynamics among individuals of a group are established and how they influence on one another and in relation to the collective constitution movement of a creative action.

With regard to the **creation triggers**, identified in the Mathematical Modeling activities of this research, they made some ideas possible in creative actions, leading students to build a Mathematical Modeling problem, a mathematical model, a solution to the Mathematical Modeling problem or a way of approaching the Modeling activity in a Basic Education class. The **creative action** was set up as **the group's convergent manifestation about ideas raised during the moments of discussions**. Besides, interventions that worked as initial triggers, when carried out by the teacher (Chart 5-B) or by researchers (Chart 5-A), aimed at mediating a situation so that the group could proceed with the creative action.

Chart 5 – Episode 5 [A11 – How much does a child spend on diapers?[4]]

A - *S1: Yeah. There are many diaper brands, in short, there are many variables. So, we decided, suggested by Res1, to prepare a questionnaire, and so we did it. [A11.Ex3]*
B - *S2: [...]There were only a few readjustments, which even the teacher advised. Otherwise, there is no way to do it because there would be too many variables. [A11* ***A11.Ex11****]*
B - *S2*: [...] There were only a few readjustments, which even the professor advised. Otherwise there is no way to do it because there would be too many variables. [**A11.Ex11**] [...] There were only a few readjustments, which even the teacher advised. Otherwise, there is no way to do it because there would be too many variables. [A11.Ex11]

Source: Setti (2022) and translated to this paper.

About initial triggers and creation triggers of creative action in MM

Initial triggers and creation triggers manifested themselves sometimes (i) from the students' interventions who were members of the group, sometimes (ii) by students from other groups and sometimes (iii) by the teachers. We also recognize that some constituent elements to develop activities seem to work as initial triggers: (iv) information presented in the text of Modeling activity; (v) the secure mediation of the teacher or student; (vi) teacher's approval of ideas presented; and (vii) the group's freedom of action. We present some of these cases.

In some situations, when the Modeling activity was followed by a text related to the approached topic, we realized that the information about the topic or the way this information was spread out may have inspired the group in some presented ideas. They may have worked as a trigger or even as a creation trigger of the creative action. For example, in activity A9, when the group was studying the theme Bees (Biembengut & Hein, 2009), the way the

[4] In this activity, students defined the topic, prepared the researched problem and collected data for resolution, as they aimed at determining the impact of financial spending on disposable diapers on family income.

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authors structured the text may have influenced the group to think about producing a comic book on this theme to develop an activity with the other classmates (Chart 6-A).

Chart 6 – Episode 6 [A9 – Bees[5]]

A - *S1: It's because in this activity there activities to do. And it seems to tell a story. I also thought about it, S2, we can get not everything because there is no time, but it would be cool, you know, because it explains a lot, and that's interesting* **[A9.Ex10].**

Source: Setti (2022) and translated to this paper.

The teacher's intentional and interested mediation is essential for the students' group to develop a Modeling activity. In this research, this kind of mediation, either by the teacher or by a student responsible for the activity, proved to be an element that worked as an initial trigger for creative action. When the group "stuck", that is, when it was unable to develop reasoning, the teacher was consulted. The reliability that the group felt during the mediation contributed to the progress of the creative action. As in Ex16 excerpt from activity A10, "Modeling a movement" (Chart 7).

Chart 7 – Episode 7 [A10 – Modeling a movement[6]]

PR: Hey, wouldn't it be more interesting to analyze this, for example, in relation to time? What do we have to do now? Define a problem, right? What kind of problem can we create in relation to this? Oh, for example..., he took the box and dropped it up there and it started to fall down. *S3:. How long does it take for the box to fall?* *PR: would that be a problem?* *S3: yeah, it would be.* *S2: but then it's just graphical analysis.* *PR: Yeah, actually, you just have to see how long it took to reach the ground, right?* *S2: it's because it goes from zero to zero point thirty.* *PR: OK, we found the answer to the problem. You don't even need to analyze the graph. What could we change to be able to analyze this? OK. Think like this, look, if we ask how long it takes to fall, we'll already have the answer, because it's the beginning and end of the video, do you agree?* *S3: okay* **[A10.Ex16]**

Source: Setti (2022) and translated to this paper.

The group's **freedom** of action was also an element that supported the manifestations of initial triggers and creation triggers, as well as inhibitors. And, from freedom, there were actions that are made possible by the Modeling environment and that constitute the creative action of the group, such as decision making, data analysis and problem elaboration. Viana and Vertuan (2021) denote that freedom is one of the aspects of the creative process that is also highlighted in the Modeling literature. While Pereira's study (2008) also emphasizes that students' freedom of action in a modeling activity is one of the key-points to encourage creativity in the classroom. Another study that points to the issue of freedom as an aspect to

[5] Students investigated the 'dance' of bees and the amount of honey they consume to produce 1 liter of honey (Biembengut & Hein, 2009).

[6] The activity consisted of modeling the movement of an object from a video made by the students using the Tracker software.

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encourage creativity in Modeling is the one produced by Vertuan and Setti (2018), when they interviewed undergraduating students from Mathematics course.

About interventions that inhibit creative action in MM

With regard to interventions and elements that worked as inhibiting interventions, we can highlight: (i) some interventions by group members; (ii) some interventions of other students; (iii) some teachers' interventions; (iv) the available time to carry out the activity; (v) uncertainty with mathematical content; (vi) the use of already known solutions; (vii) how the activity is proposed; (viii) the complexity of the situation; (ix) an uncertain mediation; (x) excessive of limitations in an activity; (xi) the lack of understanding a problem situation. Some of these cases will be presented below.

The interventions of the group members who were characterized as inhibiting were in order to do not legitimize an idea presented, believing that it was not plausible enough (Chart 8-A) or due to the limitations that the group or one of its members had (Chart 8- B).

Chart 8 – Episode 8 [A9 – Bees]

A - *S2: the problem is that we get, for example, the first liter of honey, although we also get it from the honeycomb, you know, the geometry part, you know, from the alveolus, the honeycomb geometry. And, there's the one I found there .* *S1: but in this case, I think you shouldn't have to use this one.* **[A9.Ex19]**
B - *S1: I don't know how to do it* **[A9.Ex25]**

Source: Setti (2022) and translated to this paper.

When these interventions were made by the teachers or by the students who mediated the activity, as in the seminars, for example, they occurred to 'restrain' an idea that did not 'fit' with what was expected or with excessive guidance, in the sense to "tell what to do".

The activities developed by the group had different proposals and led to different approaches. Some had time constraint for their development, around 40 minutes; others had a little more time and, there was also the development of activities in which the students had a few days and even weeks to think about the activity development. Data showed that the little time to think about the activity and to develop it proved to be a potential inhibiting element of creative action. Time, or rather the lack of it, made the group give up investing in interesting ideas to better develop the activity.

There is no definition about a Modeling activity length, which can be set up as long projects (lasting weeks or months), situations that can be investigated in some classes, or situations developed in a single class (Vertuan, 2010; Almeida et al., 2013). The time dedicated to develop Modeling depends on the dynamics of the activity and the context in which it is carried out (Vertuan & Almeida, 2016).

Thus, we understand that teacher's planning is essential for students to have enough time to think and develop their creative actions in a Modeling activity. Since students' creative actions can be 'restrained' when the teacher provides little time to an activity that has the potential to trigger multiple referrals, consequently, creativity.

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Considering the stages of creative process –"preparation, incubation, illumination and verification" (Hadamard, 2009) –, time is needed both for the preparation stage, which consists of working on the situation; while the incubation stage is when the individual withdraws from the situation, but continues to work unconsciously on solving the problem. According to the data, we observed that when there was a longer time between the activity proposition and its socialization, the students showed some episodes of enlightenment, that is, of creative insights after an incubation period.

Another element that proved to be an inhibitor of creative actions was insecurity/ uncertainty with some mathematical contents and previous contact with simplified solutions of the activity under development (Chart 9-A and 9-B). In the seminar regarding Bees situation, Group 5 showed the solutions that were in the Modeling book. They made no changes or adaptations, nor established other ways to develop the problem. Therefore, we can infer that the activity context, or the way it was proposed, did not favor the building of more original solutions (Chart 9-C).

Chart 9 – Episode 9 [A9 – Bees]

A - *S2: I think it would be possible to do the first one, which is easy and quick, and another more elaborate.* **[A9.Ex14]**
B - *S3: So guys, now we are going to present some solutions that we had in our [book] file. Yeah, the first resolution, it's literally just like the one you made.* **[A9.Ex41]**
C - E1: I was also thinking about modifying that last one, right, because there's a good part that could be used, but then I think you have to do the same, just think about how to apply it. But I think it would be possible to do these two that are together and those two regarding the dance. ***[A9.Ex20]***

Source: Setti (2022) and translated to this paper.

Thus, the proposed activity also influenced the inhibition of creative action. And, presenting seminars in a Literature Modeling activity was not as effective for the creative actions development, as the group was "stuck" to what the activity suggested as a solution, so, it did not cause or provoke the need to develop new solutions. Consequently, not understanding the situation was also shown to be an inhibiting element of creative actions. And as they did not understand what the activity purpose was, they had nothing to create. The group's effort, most of the time, was to understand what they were supposed to do. Thus, the ideas that were presented were not able to answer the problem (Chart 10).

Chart 10 – Episode 10 [A8 – Measuring the amount of rain [7]]

S1: It has to be, actually,... a millimeter is a liter per square meter, isn't it? *S2: well!* *E1: and we will have to do that. Put, I think, inside the glass. See, if we got that one millimeter. But the glass won't be that square meter, so we'll have to see how it's going to be done. Isn't that it, I think so, guys?* **[A8.Ex4]**

Source: Setti (2022) and translated to this paper.

Since there are provocative triggers (initial and creation triggers) in the creation of creative action, the inhibiting interventions were not able to 'restrain' the group's creative

[7] This activity suggests exploring and building a homemade rain gauge (Almeida et al., 2013).

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action during the activities development. We infer that this comes from the group's interest in the activities and the maintenance of interest in teacher's mediation, as well as due to the fact that provocative triggers were more frequent. Even if, in some activities, creativity has appeared more timidly than in others, it is present in the group's actions.

However, it may happen that, in some Modeling activities, inhibitory interventions are more frequent than provoking triggers. Thus, they weaken the group's creative action to carry out the activity. Following these discussions, we can infer that for provocative triggers to be more frequent than the inhibitory ones, the activity theme must be interesting to the group. It is important to have sensitive mediation by the teacher, and students need to have freedom and enough time to develop the activities. Such factors can contribute to the occurrence of provoking triggers, consequently, to the progress of creative action.

Conclusions

When investigating how the creative actions of the students' group are constituted when dealing with MM activities, we conclude that the process of constituting the route of creative action in Modeling starts from initial, intentional or unintentional triggers that cause movement of discussion in the group and produce different ideas and investments, consequently, new triggers. The initial triggers with potential to generate a creative action were called creation triggers. They are always intentional because, unlike the first ones that generate a movement to discuss a theme, they take the individuals – who have already explained in detail the theme and generated a more plausible idea – to focus their discussions, their efforts and actions on investing in an idea.

As highlighted in Figure 2, in the group's dialogue, some ideas are ignored, some are refuted and others are headed. From the moment a suggestion is headed/ decided, an initial trigger or a creation trigger is constituted, the process is repeated, and thus other initial triggers emerge, that is, the path is not linear. It looks more like a network where "synapses" occur among initial triggers, creation triggers and inhibiting interventions.

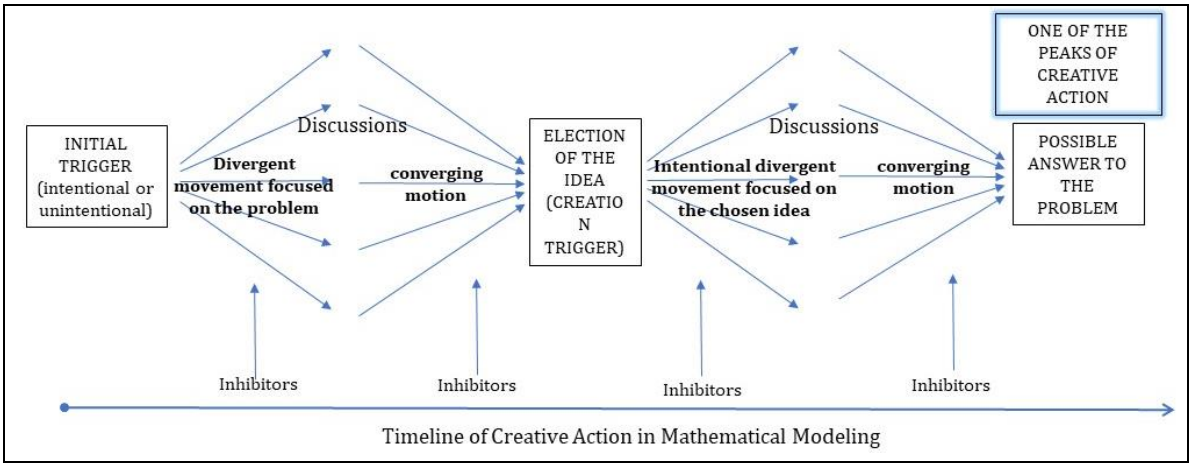

Figure 2 – Path of creative action in Mathematical Modeling
Source: Setti (2022) and translated to this paper.

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Inhibiting interventions happen throughout the course, unintentionally and intentionally, to regulate the process or change the action course. And, depending on the impact of this inhibitory intervention, the activity course can be changed gently or completely, so that new initial triggers need to be issued, in a dynamic movement.

This movement constitutes a creative action composed by individuals that belong to the group with their experiences and with different voices that constitute themselves, by the teacher who mediates the activity, by the sociocultural environment in which these individuals are immersed and by temporality.

The initial trigger generates a divergent discussion movement, focused on the problem. From this divergent movement, at some point, students need to choose an idea (creation trigger), which is the result of a convergent movement, as the group needs to invest in something. Therefore, a new divergent movement starts from the creation trigger, but now intentional and focused, because, in this stage, the group has a chosen idea with the potential to solve the problem.

Searching the solution of a Modeling problem is a movement that becomes convergent. Inhibitors are at all times along the path of creative action and it is by overcoming different inhibitors that the group manages to move forward and converge to answer a problem that is one of the highest moments of creative action in the context of Mathematical Modeling activities. As much as the idea has been generated by a trigger, it is also made up of inhibitors that often work as reorganizers of a creative action. The ideas evaluation and mathematical model validation, built to solve the Modeling problem, happen along the creative action.

If, when arriving at a possible mathematical model for a certain situation, the group analyzes that it is not suitable, a new movement in creative action begins, surrounded by new, provocative and inhibiting interventions, until the group comes out to a model or a solution that the components believe to be suitable for the situation. Finally, this artifact (Glăveanu, 2013), which is the mathematical model or solution to the problem, has the potential to be original and innovative.

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