Acta Scientiarum

http://periodicos.uem.br/ojs/acta
ISSN on-line: 2178-5201
Doi: 10.4025/actascieduc.v45i1.60956

Developmental teaching and the shaping of theoretical concepts in high school physics

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ABSTRACT. Studies and researches that have been seeking to contribute to changes in the teaching of Physics in High School, especially regarding the teaching-learning method, have benefited little from the contributions of developmental teaching as an alternative to promote these changes. This article presents results of a research that sought to answer the question: can the use of developmental teaching principles contribute to qualitative changes in the learning and development of high school physics students? The general objective was to verify the occurrence of changes in the thought of high school students in relation to a concept of Physics taught from theoretical principles of developmental education. The empirical research consisted of a formative didactic experiment with the Heat concept, guided by principles of the theories of Vigotski, Davydov, Elkonin, Hedegaard and Chaiklin. The formative didactic experiment took place in a federal educational institution located in the interior of the state of Goiás (Brazil). Twenty-two students from the discipline of Physics, from the second year of high school integrated to the technical course, participated in the research, in addition to the professor of the discipline, who had knowledge of the theories foundations of the research. For data collection, observation of classes, interviews and analysis of the task performed by the students during the formative didactic experiment were used. Only one student, for personal and emotional reasons, did not participate and there was no change in her knowledge.The results show that the students who effectively performed the heat concept learning activity by the proposed method, advanced in the zone of proximal development in relation to Heat and formed a theoretical concept of dialectical nature.

Keywords: teaching-learning physics; developmental teaching;didactics; theoretical thinking; heat concept.

O ensino desenvolvimental e a formação de conceito teórico na disciplina de Física no ensino médio

RESUMO. Estudos e pesquisas que têm buscando contribuir para mudanças no ensino de Física no ensino médio, especialmente quanto ao método de ensino-aprendizagem, pouco têm se beneficiado das contribuições do ensino desenvolvimental como uma alternativa para promover estas mudanças. Este artigo apresenta resultados de uma pesquisa que buscou responder à questão: o uso de princípios do ensino desenvolvimental pode contribuir para mudanças qualitativas na aprendizagem e no desenvolvimento dos estudantes de Física do ensino médio? O objetivo geral foi verificar a ocorrência de mudanças no pensamento dos estudantes do ensino médio em relação a um conceito da Física, ensinado a partir de princípios teóricos do ensino desenvolvimental. A pesquisa empírica consistiu em um experimento didático formativo com o conceito calor, orientado por princípios das teorias de Vigotski, Davydov, Elkonin, Hedegaard e Chaiklin. O experimento didático formativo ocorreu em uma instituição de ensino federal, localizada no interior do estado de Goiás (Brasil). Participaram da pesquisa 22 alunos da disciplina de Física, do segundo ano do ensino médio integrado ao curso técnico, além do professor da disciplina, que possuía conhecimento das teorias fundamentadoras da pesquisa. Para a coleta de dados, utilizou-se a observação das aulas, entrevistas e a análise da tarefa realizada pelos alunos durante o experimento didático formativo. Apenas uma aluna, por razões pessoais e afetivas, não participou e não houve mudança no seu conhecimento. Os resultados mostram que os alunos que efetivamente realizaram a atividade de estudo do conceito calor pelo método proposto avançaram na zona de desenvolvimento proximal em relação a calor e formaram um conceito teórico de natureza dialética.

Palavras-chave: ensino-aprendizagem de física; ensino desenvolvimental; didática; pensamento teórico; calor.

La enseñanza desarrolladora y la formación del concepto teórico en la disciplina de la Física en la escuela

RESUMEN. Estudios e investigaciones que han buscado contribuir a los cambios en la enseñanza de la Física en la escuela secundaria, especialmente en lo que respecta al método de enseñanza-aprendizaje, se han beneficiado poco de los aportes de la enseñanza desarrolladora como alternativa para promover estos cambios. Este artículo presenta los resultados de una investigación que buscó responder la pregunta: ¿el uso de los principios de la enseñanza desarrolladora puede contribuir a cambios cualitativos en el aprendizaje y desarrollo de los estudiantes de física de la escuela secundaria? El objetivo general fue verificar la ocurrencia de cambios en el pensamiento de los estudiantes de la escuela secundaria en relación a un concepto de Física enseñado desde principios teóricos de la enseñanza desarrolladora. La investigación empírica consistió en un experimento didáctico formativo con el concepto calor, guiado por principios de las teorías de Vigotski, Davydov, Elkonin, Hedegaard e Chaiklin. El experimento didáctico formativo se llevó a cabo en una institución educativa federal ubicada en el interior del estado de Goiás (Brasil). En la investigación participaron veintidós estudiantes de la asignatura de Física, del segundo año de la escuela secundaria integrada al curso técnico, además del profesor de la asignatura, quienes tenían conocimiento de las teorías subyacentes de la investigación. Para la recolección de datos se utilizó observación de clases, entrevistas y análisis de la tarea realizada por los estudiantes durante el experimento didáctico formativo. Solo una estudiante, por razones personales y emocionales, no participó y no hubo cambios en sus conocimientos. Los resultados muestran que los estudiantes que efectivamente realizaron la actividad de estudio del concepto calor por el método propuesto, avanzaron en la zona de desarrollo próximo en relación a calor y formaron un concepto teórico de naturaleza dialéctica.

Palabras clave: enseñanza-aprendizaje de la física; didáctica; enseñanza desarrolladora; pensamiento teórico; concepto de calor.

Received on September 20, 2021.
Accepted on January 12, 2022.

Introduction[1]

To this day, physics content is still taught in a way that does not encourage students to engage in the intellectual process of discovering the natural world and its properties (Gleiser, 2000). On the other hand, there is also a lack of motivation among students to study physics, and even an aversion to this subject (Bonadiman & Nonenmacher, 2007). Physics teaching is predominantly characterized by mechanical memorization of formulas and definitions, due to the existence of correct answers to be reproduced in tests and quizzes. One of the reasons for this is that, from the beginning of primary education, schools function as training centers and teaching is part of a culture of training and testing, with students and teachers focused on tests aligned with preparation for the work market (Moreira, 2000).

The predominant aims of school education in Brazil today are in line with the neoliberal project for education in peripheral countries. In this project, school education is made subordinate to forms of governability through the standardization of results, which seek to regulate the school through productivity factors (Pacheco & Marques, 2014). Within this logic, the aim is to generate percentages and indexes that make it possible to analyze the extent to which Brazilian education is adapting to economic demands. However, teachers and researchers (Amorim, Reis, Oliveira, & Santos, 2018; Oliveira, Veit, & Araújo, 2015) have made efforts to promote changes in physics teaching, seeking to achieve student learning beyond performance in large-scale tests.

Contrary to this educational project, which has an economic bias and aims to adapt to the capitalist production process, theorists who take the approach of teaching for the human development of students (Davýdov, 1982; Hedegaard & Chaiklin, 2005) argue that the purpose of school education is to promote the formation of students through the appropriation of concepts, ensuring broad and in-depth learning, with a creative and critical character. These authors understand that students' development is influenced by various aspects of their historical-cultural life context, but in school education, one of the fundamental aspects that favours this development is the preparing for teaching and learning. For them, the way in which teaching is carried out helps them to take on an attitude of investigation and search for an understanding of the object. In this way, students become active subjects in knowledge and learning. The motivation to learn is generated by the type of relationship the student establishes in working with the object of knowledge, within an activity with that object, and by a double movement of concepts, all of which is provided by the way teaching is organized.

[1]The research project was approved by the Ethics Committee under CAAE protocol : 1071501930000.0037.

The aim of this article is to present the results of a study starting from the assumption that developmental teaching, based on the formulations of Vygotsky (2001, 2007), Davydov (Davýdov, 1982; Davydov & Márkova, 1987; Davydov, 1988), and Hedegaard and Chaiklin (2005), represents a theoretical-methodological alternative to promote changes in the teaching of physics, particularly in secondary schools. We set out to investigate: what changes can be identified in student learning when teaching is organized based on the principles of these theories? The aim was to assess the degree of change in students' thinking in relation to one physics concept - in this case, the heat concept - which was taught using the theoretical principles of developmental teaching.

Theoretical references

The research was based on the theories of Lev S. Vigotski, Danil B. Elkonin, Vasili V. Davydov, Mariane Hedegaard and Seth Chaiklin. Cultural-historical theory originated in the studies of Vygotsky (2001, 2007) and was further developed by scientists who followed him. Concepts formulated by this theorist, such as mediation, internalization, the zone of proximal development, the process of concept formation and human activity, were relevant to this research.

Vygotsky (2001) defended the premise that essentially human characteristics are not innate, but are formed from the dialectical relationship between human beings and society and nature, a relationship mediated by culture. In the human being's relationship with other subjects and with nature, historically elaborated and culturally organized knowledge is internalized. What characterizes this relationship is the mediation by historically constructed instruments and signs.

In this way, Vygotsky (2001, 2007) explains that the subject's learning occurs as a social situation, with learning influencing development and the two being interrelated processes. According to the author (Vygotsky, 2001), learning can take place in different social and cultural contexts, implying two different types of knowledge and concepts: everyday (or spontaneous) and scientific (also called academic or scholastic). The course and conditions of development of these concepts are different. Everyday concepts are based on everyday experience, developed from interactions between human beings and between human beings and the world, in the contexts of daily life, forming an intuitive understanding of things, involving the process of relating words to specific objects. These concepts represent a basis for learning scientific concepts. In turn, scientific concepts are elaborated and systematized, as a result of scientifically-based research and reflection, and are learned in formal teaching-learning situations, mainly in school education. The appropriation of scientific knowledge occurs through an institutional educational process, which produces something fundamentally new in the subject's development (Vygotsky, 2007). The author's argument is that these two types of concepts need to be understood from a perspective of dialectical interrelationship. The process of forming scientific concepts involves all the basic psychological functions (attention, memory, abstraction, the ability to compare and differentiate objects), beginning in childhood and extending into adolescence. In order to form concepts, it is necessary to learn to direct one's own mental processes with the help of words and signs (Vygotsky, 2007).

As Vigotski (2007) saw it, the development of human beings occurs through the process of internalizing culture, which takes place in two distinct moments, called intrapsychological and interpsychological. Pino (2005), in agreement with this law, explains that children become cultural beings (human beings) as they incorporate culture, based on their actions which are signified by the other people with whom they relate. Everyday concepts and scientific concepts are important, but it is the scientific concepts that enable the formation of a reflective consciousness through cultural mediation.

In school education, another relevant concept from Vygotsky's theory is the zone of proximal development. It is linked to the levels of development, of which there are two. The level of actual development is characterized by activities in which the individual is able to understand and act independently with a given object of knowledge. This level represents development in retrospect and refers to mental functions that have already been formed and to established capacities. The level of potential development, on the other hand, encompasses capacities corresponding to ideal forms of culture and socially elaborated knowledge that can be acquired by the individual. It is a perspective of development to be achieved prospectively, depending on the context of life and the individual. The zone of proximal development lies between these two levels, and is determined by mental functions and capacities that are being formed, but which do not yet allow the individual to act independently; for this reason, it requires guidance, help and collaboration from another more capable person. This zone makes it possible to engineer the subject's immediate future and their dynamic state of development (Vygotsky, 2007).

The theory of developmental teaching (or teaching for human development), as conceived by Davydov (Davýdov, 1982; Davydov, 1988, 1999), represents an advance on the studies carried out by previous Russian psychologists and pedagogues belonging to Vygotsky's scientific school. Libâneo and Freitas (2017) state that the foundations of this theory come from scientific research carried out at School No. 91 in Moscow over a period of 25 years, with the participation of several other theorists, including Elkonin. The latter also theoretically formulated the periodization of human psychic development in the cultural-historical conception, based on Leontiev's theses on the role of activity in the constitution of human consciousness (Elkonin, 1987). His studies established six periods of development, each marked by a main activity that acts as a guide or conductor of development. These are: direct emotional communication activity with adults (0 to 1 year); manipulative object activity (2 to 3 years); play activity (4 to 6 years); learning activity (6 to 10 years); emotional communication activity with peers (adolescence); social production activity - work (adult) (Elkonin, 1987).

Davydov's theory consolidated the theses initially proposed by Vygotsky, but also added the contributions of Elkonin and Leontiev on human development, mediated by the guiding activity in each period. Supported by Vygotsky's thesis that school teaching and learning is the universal means of promoting the process of human development, Davydov (1988) advanced theoretically in his explanation of the organization of teaching aimed at promoting students' omnilateral human development. Thus, the structure of learning activity was formulated in detail (Davydov & Márkova, 1987). Although this activity ceases to be the guiding activity from adolescence onwards, it still plays a fundamental role as a means of promoting students' development. For Davydov (1988, p. 130), "[...] the concepts historically formed in society exist objectively in the forms of activity and their results, that is, in rationally created objects". Thus, individuals act with concepts that previously existed in society, acquiring and appropriating them in a process of development and humanization.

It should be noted that while Vygotsky established everyday and scientific concepts, Davydov (Human 1988) distinguished between two types of scientific concepts, empirical and theoretical, which are formed through empirical thinking and theoretical thinking, respectively. While abstraction and generalization are thought procedures for forming concepts, they have different characteristics in empirical and theoretical thinking, due to the different logics that underlie them, the former being formal logic and the latter dialectical logic.

In empirical thinking, empirical abstractions and generalizations of a logical-formal nature enable students to analyse and compare objects of knowledge, identifying and distinguishing their externally observable attributes that are immediately perceptible by the senses, apparent, similar or different in relation to others, the aspects common to a class, and other aspects that enable comparison, distinction, classification, hierarchization, quantification, etc., associating them with a definition and forming an empirical concept. Empirical concepts are important in terms of the ability to classify, hierarchize, define direct relationships between phenomena, etc. in order to understand facts in their particular form. And Davydov recognizes the contribution of empirical concepts as enabling students to reproduce existing mental and social representations and, in this sense, to learn paths of thought that other people have already followed. However, empirical concepts are insufficient to provide an opportunity for deeper understanding and to encourage the formation of more complex thinking and analytical skills, which is important for the omnilateral formation of the human being. For the author, empirical thinking holds students hostage to these paths, which is why he advocates the primacy of theoretical thinking and theoretical concept formation (Davýdov, 1982; Davydov, 1988).

In turn, theoretical thinking unveils the essence of the object, through the contradictions between its internal and external properties and relationships with other objects, giving meaning to the concept. "The object of knowledge is no longer reality as it appears to the senses, but reality - the scientific object - constructed by theory, in the subject-object relationship" (Borba & Valdemarin, 2010, p. 30). Thus, "[...] dialectical thinking highlights the passages, the movement, the development, thanks to which it can examine things according to their own nature" (Davydov, 1988, p. 111). It is theoretical thinking that allows the universal forms of things to be reproduced beyond their particular and immediate aspects. This type of thinking reveals the internal properties of the object of study, but in connection with its external properties, in other words, what characterizes the object's reflected and essential mediated existence. Theoretical thinking makes the theoretical concept possible and this, in turn, is a form of "[...] mental activity, by means of which the idealized object and the system of its relations are reproduced, which in their unity reflect the universality or essence of the movement of the material object" (Davydov, 1988, p. 128). Because of its dialectical nature, theoretical thought "[...] highlights the passages, the movement, the development, thanks to which it can examine things according to their own nature" (Davydov, 1988, p. 111). In order to achieve this movement and passage, thought needs to move from the abstract and universal aspect of the object to its concrete and particular aspects, in other words, from the general to the specific. Preparing for teaching through the task of studying an object of knowledge must correspond to this movement, i.e. the method of ascending from the abstract to the concrete and from the general to the specific.

The primacy given by the author to theoretical thinking and concepts is due to the fact that they encourage creative thinking and a gain in autonomy, since they lead students to assume the position of someone who investigates, in a similar way to scientists and researchers; however, not with the aim of scientific discovery, but of appropriating the products of science. The importance given to the theoretical concept is also related to its strong influence on the subjective transformation of students, with repercussions on the formation of their consciousness. In this way, students appropriate the theoretical riches accumulated and expressed by humanity in the form of culture, science, art, ethics, etc. and expressed in concepts (Davydov, 1988, 1999).

Davydov formulated the structure of learning activities by taking into account the elements of human activity established earlier by Leontiev (need, motive, task, actions and operations) and included desire, believing that need alone is not always enough to engage students in studying the object. The learning activity is intentionally planned by the teacher in order to present students with a real problem to be solved, with the solution being found along the way. The learning activity enable students to identify a general and universal relationship and, using this, to analyze particular aspects of the object, forming a comprehensive understanding of it. To do this, the teacher needs to carry out an in-depth analysis of the object in order to identify the universal and abstract relationship that characterizes the object. In this analysis, it is necessary to go to the genesis of the object and understand its development and transformation within the area of knowledge up to its most current constitution (Davydov, 1988, 1999).

Hedegaard and Chaiklin (2005) concluded that Davydov failed to consider a very important aspect in his theory that influences school learning: students' socio-cultural practices. Thus, in the theory of radical-local teaching, these authors describe them, proposing to articulate practices experienced by students on a personal, local and social level with the scientific knowledge to be learned in a given subject, which accentuates the students' motivation for learning. Methodologically, this articulation occurs through what the authors call a double movement in teaching: on the one hand, the teacher moves from the scientific concept to the students' sociocultural experience; on the other, the students move from the sociocultural experience to the scientific concept (Hedegaard & Chaiklin, 2005).

Methodological approach

Research was carried out in the theoretical field of didactics, using the formative didactic experiment, which consists of studying changes in the development of students' mental and practical actions in a real situation, through the influence of intentional didactic actions proposed by the teacher (Davýdov, 1982; Davydov, 1988; Hedegaard & Chaiklin, 2005). The researcher considers the development that students can achieve in terms of learning and skill formation within a given subject of study. The method was formulated by Davydov and his team in the context of the Elkonin-Davydov system of teaching, taking shape in school programs and experimental teaching plans (Davydov & Márkova, 1987). It is part of a family of methods devised in Soviet psychology to study the causes, conditions and mechanisms of development through education and teaching (Zuckerman, 2011). It is a method that assumes, as part of the research, a connection between the way teaching is prepared, learning and the formation of concepts by students. It is characterized by the intervention of the researcher in the teaching-learning process with a focus on learning and changes in students' thinking.

The research was carried out at a Federal Institute, located in a city of the state of Goiás, in which 22 students took part, consisting of 14 girls and 8 boys, aged between 16 and 18, and the physics teacher, bringing the total number of participants to 23. The students were enrolled in the 2nd year of high school integrated into one of the technical courses offered by this institution. The teacher had a degree in physics, a master's degree in physics and a doctorate in education, and was familiar with Davydov's theories and those of Hedegaard and Chaiklin. The students were identified as P1 to P22 and the teacher as P.

Preparing to teach certain content in a subject must include knowledge, but not only that, as it is also necessary to include the logical and psychological capacities related to the knowledge that the students are expected to develop during the study of the content (Davydov, 1988). Thus, proposing a formative didactic experiment requires analyzing the concept to be taught and learned, identifying its universal and abstract relationship.

The heat concept was selected to be the object of learning for the students. This choice was justified by the fact that, epistemologically, it is a concept that is linked to others in Physics, in the field of Thermology and Thermodynamics, forming a single, interconnected conceptual system. This content was also chosen because it is considered by students to be difficult to learn, as it is often confused with the thermal sensation of being hot, and its understanding is often expressed through the caloric theory, which was replaced by the scientific physics community in the 1840s (Pádua, Pádua, & Silva, 2009).

In order to prepare for teaching, we first carried out a logical-historical analysis of the heat concept. According to the Davydovian conception (Davýdov, 1982; Davydov, 1988), this analysis makes it possible to explain the origin of the concept, clarifying the dialectical contradictions that involve overcoming theoretical and epistemological changes, which result in the transformation of the concept and, above all, allow the identification of the abstract universal relationship that underlies it. The logical-historical study of the heat concept made it possible to identify the three main theoretical explanations of this phenomenon: phlogistic, caloric and heat-energy (Pádua et al., 2009).

The aim was to show that these theoretical explanations were formed from the constant investigative work of the researchers, reflecting the transformation of the concept by superimposing one explanation on the foundation of the previous one, in a dialectical process of continuities and ruptures, until we reached the constitution of the heat concept as "[...] a type of energy that is transferred from one body to another, exclusively because of a difference in temperature" (Carron & Guimarães, 2006, p. 266). It is important to emphasize that "[...] matter does not contain heat, it contains molecular kinetic energy and possibly potential energy, 'not heat'" (Hewitt, 2002, p. 270, emphasis added).

This universal relationship was taken as the basis for preparing for the teaching of the heat concept, as proposed in the formative didactic experiment. In doing so, we tried to correspond to the theoretical premise that in order to learn an object, the student needs to form a concept, which requires a method for thinking about it and analyzing it, with reference to the mental path taken by scientists in the construction and discovery of this concept (Davýdov, 1982; Davydov, 1988). The structure of the lessons is presented in the Results section of this article.

The following instruments were used to collect data: a questionnaire to characterize the students' sociocultural background; a diagnostic task; a semi-structured interview; direct observation of physics classes, before and during the teaching of the heat concept, based on the theoretical framework of developmental teaching; and a round table discussion with the students. The questionnaire and interview with the students covered topics such as the socio-cultural context of their lives, their main activity, the purposes that predominate in their lives, their relationship with their own learning, learning in the subject of Physics, the relationship that the students see between their learning and their development, among others. The semi-structured interview with the teacher covered the following topics: concept (theoretical framework) of training and teaching practice; teaching working conditions. Since it is impossible to present the entire set of data here, for this article we have selected some of the data that we believe to be most significant for the purpose of the text, referring to the diagnostic task, direct observation of the classes and conversations during the round table.

Results

Diagnosis of the students' knowledge of heat

In order to identify what knowledge the students already had about heat (everyday or scientific), a diagnostic task was carried out with three questions. These questions took into account the students' sociocultural context and their sociocultural practices (Hedegaard, 2002; Hedegaard & Chaiklin, 2005), previously expressed by them in the questionnaires and interviews, the period of human development they were in (adolescence) and their main activity, i.e. the activity of emotional communication with peers

(Elkonin, 1987). Solving the three questions required theoretical scientific knowledge about heat. The first question involved one of the practices of the students' families during school vacations; the second considered the students' socio-cultural practices and communication with peers during adolescence; the third question concerned the context of school practices in a ninth grade class, where students usually have their first contact with Physics, and one student questioned his classmates about the thermal sensation he experienced when touching different materials that make up the classroom door. Finally, in a round table discussion, the students were asked some questions. The following table summarizes what the students said and expressed.

Table 1. Summary of what the students knew about heat in the diagnostic task.

Question	Answers	Knowledge expressed
1. A group of young people organizing material for a camping trip in an ecological park with camping facilities. a) Laura had to bring suitable utensils. She had pans and cutlery with stainless steel, aluminum or wooden handles. She decided to choose those with wooden handles. Would you make the same choice? Why?	Sixteen students said they would make the same choice, justifying it on the grounds that wood is a poor conductor of heat.	Empirical knowledge.
	Argument for choosing a wooden handle: P16: Yes, because the wooden handle transfers less heat to the hands and prevents any burn accidents.	Everyday knowledge with signs of empirical knowledge.
	Three students justified their choice of wood handles or otherwise without linking it to the concept of heat: P3: Yes, because it would be a campsite in an ecological park and it would be appropriate to use the one with the wooden handle. P5: No, because wood is a material which accumulates and encrusts organic and inorganic material on its surface which is difficult to remove. I would take stainless steel utensils, as they are more durable, easier to wash and don't rust. P8: No, taking what catches fire more easily is the worst option.	Lack of knowledge of heat.
	Three students did not answer (P1, P18, P21)	Nothing can be said about their knowledge of heat.
b) Pedro stored the drinks in a Styrofoam box, justifying the fact that this keeps the drinks "cool" for longer and explained that the Styrofoam makes it difficult for the cold to escape and the heat to enter the box. Do you think this justification is consistent with your school knowledge of heat? Why?	Nineteen students said that Styrofoam is a thermal insulator.	Empirical knowledge.
Question	Answers	Knowledge expressed
	However, they complemented this with the following statements: Styrofoam [...] does not allow heat to escape from the inside to the outside of the box; [...] limits or hinders the transfer of heat from the internal environment to the external environment or vice versa; and [...] prevents the cold from escaping. Examples: P5: Yes, because the soft drink cans would keep their heat inside the box, not exchanging energy with the external environment, which is at a higher temperature. P6: Yes, because the Styrofoam acts as an insulator that doesn't let the heat escape from the inside to the outside.	Everyday knowledge with signs of empirical knowledge.
	Three students did not answer (P1, P18, P21)	Nothing can be said about their knowledge of heat.
c) Ruth gathered blankets to take to the camp, telling her companions that she had felt very cold when she had been in a similar situation in which she had forgotten to take a blanket. When asked about this, she explained that the blanket	Seventeen students answered the question by adding: P1: The blanket warms the body and keep the heat in the body.	Everyday knowledge.
	P6: We all have heat in our bodies, and coats and blankets are warmed precisely by the body. P7: The blanket acts as an insulator, the body gives off	Empirical knowledge.

keeps the heat from leaving her body, which allows her to sleep better and to keep the cold outside the tent. Comment on this explanation and support it.	heat and the blanket accumulates the heat between the body and the blanket, making it warm. P16: [...] the role of the blanket is to prevent this heat from escaping, so that the person stays warm by burning their own energy, which is transformed into heat. P17: That's right, the blanket is a thermal insulator and not "an object that warms you up".	
	Five students did not answer (P5, P9, P18, P20, P21)	Nothing can be said about their knowledge of heat.
2. Ninth graders at a school were learning the concepts of heat and temperature. One day, Marcos, a curious student, went to the exit of the classroom and placed one of his hands on the wood and the other on the metal door handle and proceeded to question his classmates about the temperature of the materials in contact. He said that he felt warmth in the wood and coldness in the metal, so the temperatures couldn't be the same. You, like Marcos, understood this phenomenon in this way. Justify your answer and, if necessary, write down the answer you think is most appropriate.	One student replied: Q14: They are different materials, so they absorb or give off heat in different ways.	Empirical knowledge.
	Seventeen students answered with conceptual errors: confusion between the concepts of heat, temperature and thermal sensation. For example: P1: Wood absorbs less temperature whether it is hot or cold, remaining warmer than metal which allows temperature to be absorbed. P7: This is because wood transfers less heat. Metal, on the other hand, absorbs more heat from temperature.	Everyday knowledge.
	Two students did not answer (P2 e P20)	Nothing can be said about their knowledge of heat.
3. What do you have to say about the following statement? It's very hot today, the temperature is close to 40° C. Expected answer: The statement is incomplete. The presence of heat is conditional on a system consisting of at least two bodies at different temperatures.	P5: Ah, just as you said that it's very hot, I think that's wrong, because the temperature is high, but it's not hot. P16: [...] he feels hotter because his body is giving off little energy. The temperature is high! Q19: But there's also the exchange of body heat.	Empirical knowledge.
4. Where's the heat? Expected answer: Anywhere where bodies are at different temperatures	Everywhere, said the 22 students. Some added: P2: The Styrofoam box is a way of storing heat. P7: It's because when it's cold, the body feels cold, it's because the body is going to receive heat and the sweater is a form of insulation. It closes off the heat and then it's warm!	Everyday knowledge.
Question	Answers	Knowledge expressed
5. Can we say that someone feels heat? Why? Expected answer: No. Because heat is not a thermal sensation, so we can't feel it. Hot, warm and cold are thermal sensations.	P4: Oh, guys, when I pick up a popsicle that's cold, the more I hold it, the colder it gets, and then I'll feel that warmth. P18: Actually, it's the opposite, your hand is giving off heat to the ice cream! P2: No, they're both giving off heat. P18: No, it's the hand that's warmer that's giving off heat.	Empirical knowledge.

Source: Batistella (2020).

The analysis of the diagnostic task revealed that the understanding demonstrated by the students, in their written records and in their speeches, corresponded to an everyday or spontaneous concept of heat. However, when they talked about heat as a form of energy or heat as a substance stored in the body (caloric theory), etc., they showed some scientific knowledge of heat, but of the empirical kind, for example: [...] wood is a poor conductor of heat; [...] a blanket is a thermal insulator; [...] wood and metal are different materials, so they absorb or give off heat in different ways. It was observed that some students showed some confusion regarding the concepts of heat, thermal sensation of hot and temperature, as can be seen in these sentences: [...] styrofoam prevents the cold from escaping (correctly, styrofoam prevents the flow of heat energy between the inside and outside of the box); [... [...] wood absorbs more temperature, whether hot or cold, and remains warmer than metal, which allows it to absorb temperature (correctly, metal surpasses wood in the conductivity of heat energy, so when the hand, which has a higher temperature than the door, comes into contact with these materials, it transfers heat to the metal more quickly, causing the thermal sensation of cold. It's important to know that the temperature of the handle and the wood that make up the classroom door is the same and lower than that of the human body); [...] feels heat from hot or heat from cold (hot and cold are thermal sensations, heat is a modality of energy that exists under the condition of the existence of systems with different temperature measurements, which makes you understand that it's not possible to feel heat from cold or hot).

It can therefore be inferred that students P3, P9 and P21 have little or almost no scientific knowledge about heat, as they failed to answer some questions or did not relate some answers to the concept. Nineteen students showed strong signs of empirical scientific knowledge, revealing two situations in terms of the zone of proximal development (ZPD): part of them with a ZPD involving an everyday concept and an empirical scientific concept; another part with a ZPD involving an empirical scientific concept and a theoretical scientific concept. This finding further supported the planning of experimental teaching with a focus on the theoretical concept of heat, through preparing the learning activity (Davýdov, 1982, Davydov, 1999) and the double movement in teaching (Hedegaard, 2002; Hedegaard & Chaiklin, 2005). The students' learning needs involved three types of change: 'from absence of concept to theoretical concept'; from everyday concept to theoretical concept; from empirical concept to theoretical concept. This is what was sought with the formative didactic experiment.

Preparing teaching for learning heat as a theoretical concept

Davydov (1988) formulated the general structure of the learning activity to be undertaken by students, consisting of six actions: 1st) Transformation of the task data to discover the universal relationship of the object of study; 2nd) Modeling of this universal relationship in objectified, graphic or literal form; 3rd) Transformation of the model of the universal relationship to study its properties in pure form; 4th) Solution of specific tasks that can be solved by the general method; 5th) Evaluation of the performance of the preceding actions; 6th) Evaluation of the formation of the general method of solving the learning task. Based on these actions, tasks are carried out which consist of each action, the objective to be achieved in this action and the conditions for carrying out the action. The author proposes that these actions, with the exception of the sixth, should be carried out collectively and that the student's thinking should move from the general to the specific and from the abstract to the concrete.

In preparing for teaching the heat concept, a task was formulated, structured in the form of a learning activity, consisting of six actions for the students to carry out (Davýdov, 1982; Davydov, 1999; Hedegaard & Chaiklin, 2005) in order to form the theoretical concept of heat. In the first action, by introducing a problem and challenging the students to solve it, the researcher's intention was: to mobilize the students' mental/practical activity; to get them actively involved with the object of study (heat); to motivate them in an investigative search to find the solution. It was hoped that they would arrive at an in-depth explanation of the problem using a theoretical method of thinking and analyzing it.

The initial problem involved rural activity, which is very familiar to the sociocultural context of life reported by the students in the interviews. They were instructed to carry out the first five activities collectively and collaboratively, working in groups designated by the letter G and the number assigned to the group (G1, G2, G3, etc.). The grouping was changed for each activity in order to promote interaction and diversify the presence of students with different zones of proximal development in relation to heat knowledge. This composition also took into account the emotional relationships between them. The students are indicated with the letter P (participant) and the corresponding number, and the teacher is indicated only as Teacher. The activities are described below.

First action

The purpose of proposing this first activity to the students was to mobilize them to investigate and discover the following universal relationship (Davydov, 1988, 1999), which forms the basis of the theoretical concept of heat: a type of energy that is transferred from one body to another due exclusively to a difference in temperature (Carron & Guimarães, 2006). They were expected to reach this conclusion by searching for relationships and connections, imaginatively carrying out a path of analysis similar to that of the theorists who had previously investigated and formulated the heat concept.

The challenge presented was a problem faced by a small rural producer, who raised a flock of free-range chickens near his home (a common practice in the region where the school is located). The producer had no systematized knowledge about his activity and his material resources to carry it out were restricted. The goal was for the students to identify that, with little knowledge of the subject, the farmer made mistakes when conducting the process of breeding the birds, which resulted in failure in some attempts, the failures being related to the physical phenomenon of heat. In this way, we also sought to link the practices experienced by the students and local knowledge with the search for theoretical scientific knowledge about heat in order to awaken the motive and desire to learn, as well as to make them attribute meaning to the search for theoretical knowledge. In other words, the aim was to promote the connection between local knowledge in the students' sociocultural context and school scientific knowledge in order to establish a double movement in teaching from a radical local perspective: the students' movement from their local sociocultural experience towards the scientific concept; and the teacher's movement from the scientific concept towards the students' sociocultural experience (Hedegaard, 2002; Hedegaard & Chaiklin, 2005).

The students had to analyze the scenario and come up with explanatory hypotheses, using the knowledge they had so far. To give them more elements to support their analysis, they were shown a short video about free-range chickens in different stages of reproduction. Even before the end of the video, some of them had already expressed what they had observed, for example: "Wow! The eggs got bigger?" (P18) (Batistella, 2020, p. 139). They dialogued, discussed, elaborated and expressed different ideas about the problem. These ideas were linked to aspects of explanatory theories about heat. Table 2 shows some examples of the discussion in the groups, with elements that indicate that among the students there were two types of knowledge about heat: one everyday, with confusion and conceptual error, and another that, although it is empirical scientific knowledge, was from the perspective of the caloric theory, which has been superseded since the 1840s by the heat-energy theory. There was also no evidence of scientific knowledge linked to the heat-energy theory. Thus, elements that appeared in the diagnostic task also appear here.

Table 2. Some of the students' hypothetical answers to the problem faced by the Rural Producer.

Heat theory (heat as a fluid)	G1. For the egg to become a chick, the hen needs to hatch it, transferring heat to the egg. G2. When all the eggs hatched [became chicks] there was a perfect distribution of heat between the eggs, making the breeding medium ideal; when only a few hatched it was because the heat wasn't well distributed among the eggs. The hen probably laid too many eggs and couldn't keep them all warm. G4. [...] nest in an unsuitable place which is made of cement and does not contain the warmth within the cubicle. Install yellow lights (because of the heat generated) in the wooden cubicle, (because the heat transfer from the hen to the wood is less than from the hen to the cement).
Heat-energy theory	No hypotheses were made considering heat as energy.
Conceptual error: Mistaking temperature, heat and thermal sensation	G1. The farmer could make a hen house for the hens, so they wouldn't abandon their eggs and there would be more heat transfer because there would be more bodies involved. G2. We recommend building a hen house to place the nests scattered around, allowing heat to accumulate inside. G4. [...] install yellow lights (due to the heat generated) in the wooden cubicle. G5. The caloric theory explains success and failure, since heat must be transferred from the hen to the eggs in the process of reproduction.

Source: Batistella (2020, p. 141).

Next, the students were challenged to perform a theatrical representation of the problem situation experienced by the producer, which they did with great involvement, laughter and jokes, showing that the form requested for the representation mobilized their interest and motivated them. Some squatted to represent the chicks, while others hugged and stood to represent the hen. With this, they had to stand very close together. Asked to analyze what had happened, considering the video and the discussions they had held, they found a link between heat and the farmer's failure. The fact that they recognized heat as a determining factor in the farmer's failure shows that the students were working with elements of the universal relation of heat in their analysis, i.e. "[...] a type of energy that is transferred from one body to another exclusively because of a difference in temperature" (Carron & Guimarães, 2006, p. 266).

At the end of this action, they were presented with a text prepared by the researcher in which the three theories accepted by the scientific community to explain the nature of heat were discussed (phlogistic, caloric, heat-energy). The teacher mediated the discussions with questions and comments, with the intention of getting them to identify the universal relationship that underlies the heat concept. The following dialog contains elements that show the beginning of the qualitative transformation of prior knowledge that the students expressed in the diagnostic task.

P11: Does it matter if it comes out of the cold or the hot body?
P20: Cold doesn't give energy up to hot, it's the other way around.
P7 and P11 talk and P11 says he doesn't understand.
Teacher: P11 didn't understand, let's see... P11, what is the basic general relationship of the heat concept?
P11: It's the transfer of energy..., ah! Speak up P20!
Teacher: P11, Energy, energy transfer because of the different temperatures. Heat is in the body?
P4, P1 and P20: No: heat is a process!
P11: Is that why there's an arrow?
Teacher: Yes, the arrow in this drawing would indicate the process.
P11: Ahhh, now I get it. Got it, got it... The arrow indicates the process! [the student was happy to have understood the model and, consequently, the universal relationship of heat]

This snippet of dialogue, which took place during the sharing of models of the universal relationship of the heat concept prepared by groups G1, G2 and G3, shows that student P11's knowledge, which was of the everyday kind, is moving towards empirical knowledge, which can be seen when she understands the need for one of the model's elements (arrow), the existence of which is essential for identifying heat.

Second action

Having discovered in the first action that there is a universal relationship explaining the concept of heat, in this action the students had to build a model representing this relationship. This model aims to represent this relationship as an essential element of the object being studied, which is often not immediately apparent (Freitas, 2012). Therefore, it is not just a question of indicating the external and apparent characteristics of the phenomenon, but of demonstrating what lies behind the elements of the object that are expressed and which can be immediately perceived.

The model can be expressed through text, graphics, symbols or letters, theatrical representation, etc., as long as it correctly expresses the universal relationship of the object under study (Davydov, 1988; Hedegaard & Chaiklin, 2005). In this case, the students were asked to draw a picture.

Organized into three groups (G1, G2 and G3), the students formulated and built a model which they thought represented the universal relationship of heat. During the socialization of the groups' models, it was noted that flaws in the model were indications that the universal relationship had not yet been correctly identified or that the model was not sufficiently well constructed. The teacher then asked the students to evaluate the models, analyzing whether they corresponded to what had been asked of them so that they could see any mistakes which, although subtle, mischaracterized the universal relationship. At this point, therefore, the students were carrying out, within the second action, what is defined in the fifth action by Davydov (1988, 1999) to be carried out transversally in all of them, that is, the conscious, reflective and critical examination of their performance and their progress throughout the actions, with reference to the defined goals. The mistakes which the teacher and students identified and discussed so that they could be corrected were: a) Group G1 represented heat using arrows in the same direction and in both directions, indicating heat transfer from both bodies even though they were at different temperatures. In this case, the correct way to indicate the universal relationship of heat would be to place the arrow unidirectionally, at only one end of the line, indicating that the flow of heat energy occurs spontaneously from the body with the highest to the lowest temperature. b) Group G2 used 'hot and cold' to identify the bodies and the movement of the molecules that make them up. Hot and cold are thermal sensations, so it would be correct to use temperatures T1 and T2. G3 added the physical quantity 'distance' to the relationship. The universal relation of heat can be described as the modality of energy that is transferred from one body to another due exclusively to a difference in temperature, i.e. from the body with the highest temperature to the body with the lowest temperature. The model should be representative of this essential internal connection of the object heat.

They added the moment of thermal equilibrium, with both bodies reaching the same temperature and resulting in the extinction of heat in the system under consideration. Figure 1 shows an example of one of the models constructed and the final model drawn up by everyone.

The relevance of the action of constructing the representative model of the universal relationship of the concept lies in promoting the student's awareness of the reality captured and reproduced by the human mind, highlighting the need for the human mind to recreate it in an ideal form when forming awareness of a real object. This recreation reflects the real object in another form, the form of theoretical thought, which in turn expresses, on an ideal level, the movement of the real object, its contradictions and transformations

(Davýdov, 1982; Davydov, 1988; Hedegaard & Chaiklin, 2005). Another important role of modeling is that it gives students the opportunity to create and not just reproduce knowledge. Creating the model requires analysis and synthesis, imagination, mental experimentation, which turns the student into a subject who formulates, plans, elaborates representations rather than someone who simply repeats or memorizes. This action helped to make the students aware that, in order to form a theoretical concept of a real phenomenon, a method of analyzing and thinking about this phenomenon is necessary, and it initially requires the procedure of abstracting the universal relationship, which contains its most essential and internal nexus. Thus, at the same time as carrying out the action, the students were also examining their path and their method of thinking, analyzing and grasping the object, which corresponds to the fifth action (described below).

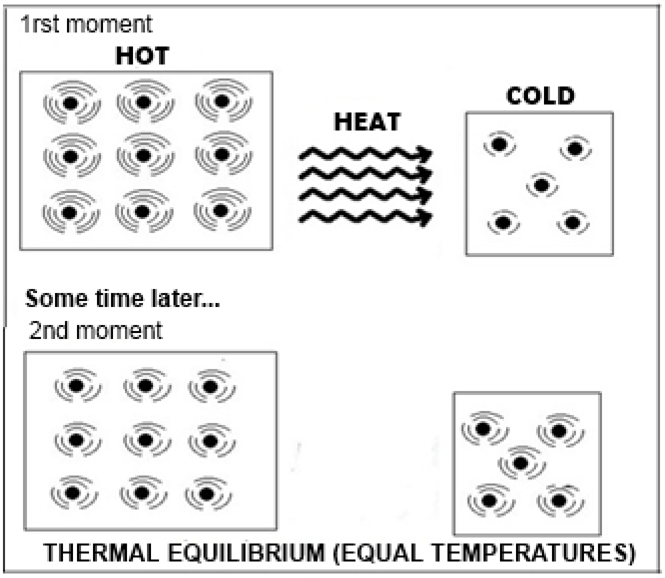

Figure 1. Group G2's model of the universal relationship of the heat concept.
Source: Batistella (2020, p. 152).

After the discussions and corrections to each model, the students were asked to reach a consensus on the formulation of a single model that expressed two bodies with different temperatures, indicating the movement of energy from the body with the higher to the lower temperature (Figure 2).

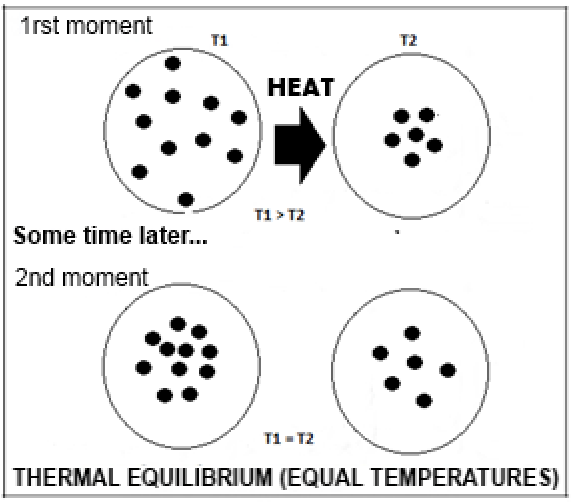

Figure 2. Final model of the Universal Relationship of the Heat concept.
Source: Batistella (2020, p. 156).

Third action

If the core of the universal relation is altered, its result also changes (Freitas, 2012). Analyzing this change is important for students to deepen their understanding of the universal relation, as they need to understand the consequences of the change. To do this, the students are asked to make the change to the model constructed in the second action (Davydov, 1988). The teacher asked the students to start the third action by watching and analyzing a video about penguins breeding in Antarctica, where the average temperature is minus 40°C.

After this stage, the students were instructed to imaginatively carry out an experiment: take the hen/egg system (present in the first action problem) to hatch in Antarctica, the environment in which penguins breed. The students' thinking was geared towards analyzing the contradiction regarding the amount of energy in the form of heat needed to maintain thermal equilibrium between the hen and the eggs, observing the climatic conditions of the environment. To do this, they had to use the model built in the second action as a reference. They immediately argued that it was impossible for the hen's eggs to hatch due to the amount of energy that the hen/egg system would transfer to the environment through heat, causing the animals and their eggs to die. The following dialog clipping shows the students' understanding:

Teacher: So what is the direction of the energy transfer?
Students: From the chicken to the environment.
P2: Oh, that's great! The chicken will give up energy until it reaches thermal equilibrium with the environment.
Students: It gives off energy in the form of heat.
Teacher: So, let's take the chicken and the eggs and take them to Antarctica. What happens?
P2: Both the egg and the hen will be at the same temperature as the environment
Teacher: So the chicks will hatch?
Students: No.
Teacher: So what does the egg need to stay alive?
Student: Heat! No! Energy exchange
Another student says: There can't be any energy exchange! It has to maintain its temperature!

Fourth action

This action consists of presenting students with problems involving the learning object in different types of particular situations. Having understood the general abstract relationship and built their model, students should use it as a general method of thinking for analyzing the object in particular situations, i.e. as a mental tool that allows many specific cases to be solved from a general theoretical principle (Davýdov, 1982; Davydov, 1988; Freitas, 2012). In this way, action five consisted of solving particular problems involving the phenomenon of heat.

First, the students were asked to read the text 'Ten tips for coping with the heat', which is available on the internet (https://brasilescola.uol.com.br/saude/10-dicas-para-enfrentar-calor.htm). The students were instructed to read, identify and analyze statements that disagreed with what they had learned so far about heat, and propose corrections based on the universal relationship and its links with the different specific ways in which the physical phenomenon of heat can be identified.

The students expressed great euphoria when they realized that they could spot misconceptions about heat. This type of observation is an indication of a change in the students' thinking and that they have taken ownership of the universal relationship of heat. Table 3 shows a summary of what the students identified and the expressions they came up with for correcting the text.

Table 3. Identification and suggestion of expressions in the analysis of the text 'Ten tips for coping with the heat'.

Original Expressions in the Text	Expressions Prepared by the students
Exposed to the heat of the sun	Exposed to solar energy
Heat causes food to spoil more quickly	Some foods can spoil easily when exposed to high temperatures
Light-colored clothes are cooler than dark clothes	Light-colored clothes absorb less heat energy than black clothes
They increase the heat in the room	Increase room temperature
Let the heat out	That the internal energy of a body change [decrease] through heat
Extremely hot days	Days with very high temperatures

Source: Batistella (2020, p. 163).

As a follow-up to this action, the students carried out an experiment in two different moments: first, they were asked to rub their hands together for a few seconds and then to touch their faces. The students identified the increase in temperature of the hands when rubbing (friction) and the presence of heat when touching the face (movement of energy from the hands to the face), which showed that they were establishing the connection between the universal relationship and a certain specific heat relationship. The following dialog presents elements that indicate that there has been a transition from the universal to the specific relationship and the identification of a contradiction:

P9: There can't be any heat, the hands are at the same temperature they were before.
Teacher: So what happened to your hands after you rubbed them together?
P5: They got hot.
P13: What happened was the temperature rose (Batistella, 2020, p. 163).

As the last operation in this action, the students were given an excerpt from an article on the spawning and reproduction of turtles by the Tamar project. This text was chosen because student P2 had expressed a desire (in a previous lesson) to understand and learn more about the reproduction of this animal. After reading the text, the students had to explain why turtles nest in the sand under intense solar radiation. This was a variation on the initial problem involving the reproduction of chickens, but in a different context and with different particularities, but the thinking, analysis and deduction procedure to be used was to be the same, i.e. based on the universal relationship of the heat phenomenon.

Below is a snippet of dialogue showing how the students analyzed the problem involving turtle reproduction.

P1: Guys, the turtle is just like the chicken. Leaving the eggs under the sun's radiation is like the hen lying on top of the eggs....
P4: Turtles nest under solar radiation, in the sand there is an exchange of heat between them, but it's not as high [as] if they were in direct contact with the sun's rays.
P7: With the sand under the sun (sic), the eggs will always be warm, the sand plays the role of the mother, to warm them up, you know (Batistella, 2020, p. 163-164).

In the fourth action, students should be aware that the universal relationship of the object becomes a mental procedure for solving a variety of specific and concrete problems, making generalizations about this procedure. They will then be able to build up a concept of the whole object, understanding the unity formed by its general relationship in connection with the particular relationships. They acquire the ability to understand the object in motion, making transitions from the general and abstract to the specific and concrete, and vice versa (Davýdov, 1982; Davydov, 1999).

Fifth action

The fifth action consists of evaluating previous actions, with the students themselves examining how they have carried them out, developing a conscious and critical reflection of themselves in order to achieve the objectives proposed for the study of the object (Davýdov, 1982; Davydov, 1999). It can be considered that this action corresponds to a collective and individual self-assessment by the students with reference to the guidelines present in the task and the objectives to be achieved (Freitas, 2016).

The fifth action needs to take place during the course of the learning activity and requires students to be attentive, maintaining the connection with the object of study and the proposed objectives. It was exemplified in the description of the Second Action above, but was repeated in all the others, allowing the students to always strive to be aware of their actions and their learning, with reference to achieving the objective of the task in its entirety (Hedegaard, 2002; Hedegaard & Chaiklin, 2005).

Here we briefly present an excerpt from a dialog that also shows that the students were concerned with maintaining individual and collective work, and were examining their hypotheses, conclusions and ways of thinking: "P20 - a hen leaves the nest if other hens come and touch her eggs and also if a dog comes and eats an egg... P13: These hypotheses don't have much to do with physics, no!" (Batistella, 2020, p. 166). During one of the actions, two students left the room (P19 and P22) and their colleagues showed concern about the fact that the work needed to be collective and the absent students would need to regain focus when they returned: "P6: I hope they still show up. Then we'll ask them what heat is? We can't do our research without them" (Batistella, 2020, p. 167).

This snippet of dialogue during the socialization of group G1's model for the second action shows that the universal relationship of heat had not yet been identified by the group and that the interaction and collaborative discussion with colleagues from other groups helped to overcome their doubts.

P12: Do we need to improve it here [between the bodies] to represent heat?
P20: An arrow going from the hottest body to the coldest (sic).
P11: Does it matter if it comes out of the cold or the hot body?
P20: Cold doesn't give energy up to hot, it's the other way around.
P7 and P11 talk and P11 says he doesn't understand.

Teacher: P11 didn't understand, let's see... P11, what is the basic general relationship of the heat concept?
P11: It's the transfer of energy..., ah! Speak up P20!
Teacher: P11, Energy, energy transfer because of the different temperatures. Heat is in the body?
P4, P1 and P20: No: heat is a process!
P11: Is that why there's an arrow?
Teacher: Yes, the arrow in this drawing would indicate the process.
P11: Ahhh, now I get it. Got it, got it... The arrow indicates the process! [the student was happy to have understood the model and, consequently, the universal relationship of heat]

It is important to note that during the learning activity, some students reflect on their method of thinking about the object, that they strive to carry out the task as proposed, to correct and return to the path when they identify flaws.

Sixth action

In accordance with Davydov (1988), the first through fifth actions were carried out collectively and the sixth action was completely individual. In this action, there was an individual assessment of learning to verify the formation of the theoretical concept by the student. The teacher had to check whether the student had formed a theoretical concept of the object heat, whether they were able to abstract from its universal relationship and then generalize it as a procedure for analysing and solving various particular and concrete problems involving the physical phenomenon of heat.

The students were asked to answer the same questions they had been asked to answer in the diagnostic task. By contrasting the solution of the task now with the one carried out previously, there was evidence of a change in the way they were thinking about and analyzing heat as an object of knowledge. This change represented an advance in relation to the students' initial knowledge. Some of the students' answers to questions number 1 (letters a and d) and number 2 (letter c) in Table 4 are examples.

Table 4. Answers to question 01 of the diagnosis requested after the theoretical study of heat.

Question	Answer to the diagnostic task	Answer to the task corresponding to action 6	Evidence verified
1st a) Laura had to bring suitable utensils. She had pans and cutlery with stainless steel, aluminum or wooden handles. She decided to choose those with wooden handles. Would you make the same choice? Why?	"No, because wood is a material which accumulates and encrusts organic and inorganic material on its surface which is difficult to remove. I would take stainless steel utensils, as they are more durable, easier to wash and don't rust." (P5)	"Yes, because spoons with wooden handles don't conduct much energy (heat), so if someone uses them to cook, they won't burn their hands, but they will if using stainless steel and aluminum spoons, as they are good thermal conductors." (P5)	Transformation of thought in relation to the object heat and movement towards the development of a theoretical conceptual understanding.
	"No, because there are better options, since in an environment where there are fires and other flammables, taking the one that is easiest to catch fire is the worst option" (P8)	"Yes, because the wooden one doesn't conduct as much energy in the form of heat as the others" (P8).	
1st d) Ruth gathered blankets to take to the camp, telling her companions that she had felt very cold when she had been in a similar situation in which she had forgotten to take a blanket. When asked about this, she explained that the blanket keeps the heat from leaving her body, which allows her to sleep better and to keep the cold outside the tent. Comment on this explanation and support it.	We all have heat in our bodies, and coats and blankets are warmed precisely by the body. We feel warmer because we're in direct contact with the blanket, which absorbs our heat, which wouldn't happen if we were in contact with the cold air (P6).	It's wrong because energy is transferred from the body to the blanket (P6).	Transformation of thought in relation to the object heat and movement towards the development of a theoretical conceptual understanding.
2ª c) Answer: When drinking coffee with milk, one of the students didn't notice that immediately before the	The coffee, it was hotter (P14).	No, you have to know which of the two had the higher (hotter) temperature (P14).	Transformation of thought in relation to the object heat and movement

mixture was made, the liquids were at different temperatures. Under these conditions, is it possible to correctly state which of the two liquids gave off heat? Why?		towards the development of a theoretical conceptual understanding.

Fonte: Batistella (2020, p. 170-171).

The answers shown in Table 4 (P5, P6, P8 and P14), when contrasted with those given in the diagnostic task, provide evidence that the students were able to advance from empirical to theoretical thinking in relation to the heat concept, which is an indication that a change was beginning in their ZPD (Batistella, 2020).

Although the teacher and students made an effort to arouse interest and motivate the whole class during the formative didactic experiment, students P3, P16 and P21 didn't manage to form the theoretical concept of heat, probably because they didn't engage in the learning activity. Student P3 revealed in an interview that she has problems with her family and, in the classroom, she usually remains isolated from the class and does not interact with her classmates or the teacher. Students P16 and P21, on the other hand, showed that they were used to doing lists of exercises and surveys and being graded, which was not the aim of the didactic-formative experiment. We conclude that, at the end of the formative experiment, the ZPD of these students could have expanded if the formative experiment had continued.

At the end of the didactic experiment, the students were asked to send a reply to the farmer, suggesting a solution to the problem presented in the first learning action. Some of their ideas are highlighted below.

> P4: In the two nests that the farmer had problems with, the nests didn't offer the right conditions. The hen needs to exchange as little energy as possible with the environment during brooding, so the nests should be indoors, protected from the wind and there should be food and water near the hen.
> P5: Of course the nests have to be enclosed and the number of eggs under the hen has to be small, they have to receive energy at all times to keep warm.
> P6: The hen has to get used to laying her eggs in a clean, enclosed place, then when she hatches she'll lie on top of the eggs and they'll receive the amount of energy they need to stay warm and all turn into chicks.
> P12: It's important to keep the hens indoors, with ventilation and a small amount of heat, just to keep the temperature of the eggs the same as that of the hen (Batistella, 2020, p. 173).

There was significant student participation, both in the work within the group and when it came to sharing the actions with everyone. The teacher mediated by initiating the dialog, which was then enriched by the participation of the students, bringing their local experiences, explanatory hypotheses, conclusions, etc.

Discussing the results

The aim of the research was to verify the occurrence of changes in high school students' thinking in relation to a physics concept, heat, taught using the theoretical principles of developmental teaching, according to the theoretical framework explained. The results of the diagnostic task provided elements for continuing with the formative didactic experiment, showing that the students either had an empirical scientific concept or an everyday concept about heat, or they didn't have any knowledge of it.

Among the twenty-two students taking part in the research, only one student, P3, showed no change in her knowledge of heat. She explained that she had personal and emotional reasons for not carrying out the learning task and so did not develop the attitude of a subject in a learning activity. It is inferred that with more time, more didactic mediation and an in-depth understanding of this student's motives, she could probably participate and have an investigative attitude like her classmates, and could even form the theoretical concept of heat.

As for the other students, the data presented in the tables indicates that there has been a shift towards the theoretical concept of heat. There were eight (8) students with empirical knowledge. Of these, all reached a theoretical understanding of heat. The students who had signs of an everyday concept of heat were thirteen (13) and they all also formed a theoretical understanding of the concept.

Another change was seen in the students' motivation and participation. By preparing for the teaching, introducing problems that were linked to the students' sociocultural context and local knowledge, there was a positive repercussion that favored the establishment of a relationship with the object of study and, in this way, the realization of the learning activity, which has this relationship as a defining criterion. The students developed the attitude of someone who investigates and wants to discover an explanation for the phenomenon of heat, which is fundamental to forming a theoretical concept and moving beyond the level of just reproducing the concept based on the conclusions of theorists in the field of physics. It was also important to take into account the periodization of the students' development and the activity of simultaneous communication, because, as well as fostering collective and collaborative work, it helped to give the fullfilment of the tasks and the search for a solution to the problem a personal meaning for them.

The preparing for teaching according to Davydov's theory, combined with the double movement in teaching proposed by Hedegaard and Chaiklin, proved to be a promising alternative for teaching the heat concept in high school physics. These theories represent references for developmental didactics in order to realize the perspective of the students' integral formation, the formation of autonomy in learning, creativity in solving life's problems in a social context, the transformation of theoretical concepts into mental procedures to be used in everyday life. In this way, we have a perspective that overcomes the instrumental, pragmatic, reductionist and limiting perspective of student learning and development.

However, it must be stressed that the consistent use of these theories as a didactic foundation for planning and preparing for physics teaching poses challenges for teachers in terms of their capacity for epistemological analysis of the content to be taught and in-depth knowledge of these theories. This theoretical and methodological understanding requires investment in initial and continued training for physics teachers. Silva, Pereira, Novello and Silveira (2018) state that the majority of teachers are demotivated in relation to their teaching career and, for this reason, there is an urgent need for public policies that promote the valorization of teachers, especially in financial terms, so that they can dedicate more time to their training and lesson planning. The development of dialectical theoretical thinking as a method of thinking about and analyzing an object of study refers to the idea of a subjective process of change in students' psychological capacities, but it is important to consider that, according to Vygotsky (2007), the impact on development is a broader process that cannot be grasped immediately. It is a future-oriented process, which will manifest itself every time the student uses the method of thinking about the concept in other situations and in a way that is integrated with learning the conceptual system of Physics.

Final considerations

Schools today are constantly striving for high-quality teaching, but this search has been dominated by a concept of school performance, expressed in achievement in external assessment tests focused on quantitative measurement of learning. This has led teachers to play a technical role in the teaching-learning process and to fulfill pragmatic educational goals with a neoliberal, market-based bias (Menegão, 2016). As a result, students miss out on the opportunity for a type of learning that promotes their development in a more open and broader way, taking into account their needs for personal and social transformation.

Particularly in the teaching of high school physics, much remains to be achieved in terms of change. In the scientific literature on high school physics teaching, the main problems studied by researchers include learning difficulties (Bonadiman & Nonenmacher, 2007; Menegotto & Rocha Filho, 2008; Oliveira et al, 2015; Darroz; Trevisan & Rosa, 2018), students' lack of interest in learning physics concepts (Cima, Rocha Filho, Ferraro, & Lahm, 2017); the distance between school content and students' daily lives (Bonadiman; Nonenmacher, 2007; Menegotto &; Rocha Filho, 2008; Sena dos Anjos, Moreira, & Sahelices, 2017; Cima et al, 2017); contextualization of physics knowledge (Reis & Reis, 2016; Vizzotto, Mackedanz, & Miranda, 2017); introduction of teaching strategies and resources to facilitate learning (Sousa & Silva, 2014; Amorim et al., 2018). This research argues the need for changes in the teaching of Physics, suggesting diversified methodological proposals in order to boost student participation, making them active in the teaching-learning process, as well as creating forms of motivation and involvement with learning.

By agreeing with these researchers, we reaffirm the need for a perspective that goes beyond understanding the purpose of physics teaching, arguing in favor of the theoretical perspective of developmental teaching, which highlights the formation of the dialectical theoretical concept as essential. However, few studies are explicitly based on the concept of teaching for the development of students. For example, based on Vygotsky, there are studies focusing on social interaction between students and the zone of proximal development (Monteiro, Monteiro, Germano, & Gaspar, 2010; Pureza & Magalhães, 2008), mediation, affectivity and experience (Pereira & Abib, 2016). Based on Davydov, there are studies such as Marengão's (2011), which focused on the formation of students' mental actions, Brignoni's (2018), which developed a didactic-formative experiment with high school students to form concepts of light propagation and image formation, and Borges' (2016), which carried out a didactic-formative experiment in the first year of integrated high school on the content 'Newton's Laws'. Thus, in addition to a few studies, no works were found that incorporated the contributions of Hedegaard and Chaiklin.

In this vast field to be explored, the results of this research can add new contributions to the search for changes in high school physics teaching, strengthening the perspective of teaching to promote the development of students' abilities, through the formation of theoretical thinking of a dialectical nature. This is what was sought in this study, using the heat concept to carry out a formative didactic experiment in secondary education. There is a pedagogical and social need for changes in teaching and learning in high school physics so that students are motivated to learn, feel the desire to understand the concepts of physical phenomena in greater depth, and become capable of using these concepts in general social life and in their local context. Developmental teaching represents an alternative to promote a broader education for students, one that is not restricted to a focus on tests and exams, and that does not reduce their development to neoliberal performance criteria, focused on productivity and adapted to demands that are solely economic in nature.

It is possible to widely explore and make use of the theories of Vygotsky, Davydov, Elkonin, Hedegaard and Chaiklin in order to create a didactic-pedagogical praxis in high school physics teaching, oriented towards a social commitment to promoting transformations in students' cognitive, social, ethical, political and cultural education, helping them to become aware and active subjects in their social and local reality, using theoretical concepts to do so. The results described here, although they cannot be widely generalized to the teaching of physics in secondary schools, provide important clues so that changes can be introduced in the direction of a teaching-learning process that is closer to a creative, critical and conscious formation of adolescents, which allows them to adopt a subject's attitude and move beyond everyday and formal empirical knowledge towards dialectical theoretical knowledge. The main contribution of this research is to empirically show the possibility of developmental teaching as an alternative for teaching physics in secondary schools, in order to boost the quality of students' learning and thus contribute to their education and human development.

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