Building biochemical concepts through project-based learning: A paradigmatic analysis

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Abstract: Learning metabolic biochemistry requires constant articulation in the molecular universe. Its concepts are better understood when developed in a paradigmatic perspective that enables conceptual articulations and contextualizations. In this sense, a perspective that contemplates the systemic and complex paradigms provides a better understanding of the whole, recognizing the interdependence between the parts, meaning the biochemical processes. This qualitative study aimed to analyze the construction of concepts about metabolic integration from a biochemical and paradigmatic point of view by a pedagogical action based on project-based learning (PBL). The specific formal content of the biochemistry discipline (Full Undergraduate Course in Biological Sciences, Pernambuco, Brazil) was transposed to a context capable of dialoguing with the students' reality. Data were obtained by individual production from the conceptual deepening activity. The productions were analyzed in the light of biochemical categories and science paradigms. The results point to the potential of project-based learning to guide specific actions for studying concepts of a poorly structured domain in its cognitive elaboration in an articulated and paradigmatic perspective.

Keywords: science paradigms, concept construction, biochemistry teaching, metabolic integration, project-based learning.

Introduction

Biochemistry is a study area that addresses two knowledge areas, Biology and Chemistry, which complement each other to explain many phenomena that occur in living systems. This means there are requirements for these two knowledge areas, each with its peculiarities, so the student needs to structure links between them in order to understand a phenomenon.

It is known that inanimate molecules are among the constituents of the living organism, whose interaction is solely governed by the physical and chemical laws of the inanimate universe and ensures the maintenance and perpetuation of life. In this sense, elucidating how these processes and phenomena occur is one of the purposes of Biochemistry (Nelson & Cox, 2014).

Regarding the study of this branch of Biological Sciences, it is common for concepts to be understood as a collection of chemical structures and reactions that are difficult to understand. This perception can be partially credited to its interdisciplinary characteristic and the complexity of the contents dealing with micro and macromolecular phenomena that are difficult to abstract and understand. In this context, Araújo *et al*. (2017) state that because it is an abstract science involving molecular concepts that permeate the micro and macro universe, it is important to search for contextualizations to assist in the teaching-learning process.

Sá (2007) also points out and explains some identifiable difficulties in Biology teaching that apply to Biochemistry: abstraction, verticalization, fragmentation, and decontextualization. Abstraction and verticalization are natural Biochemistry concepts. The first is related to cellular, molecular, and atomic structures and symbolic concepts that refer to metabolic processes, such as the Krebs cycle. Verticalization is related to constructing relationships between the two universes (macro and micro) present in Biology. On the other hand, fragmentation and decontextualization relate to teaching practice, meaning difficulties arise due to how the teacher sees and works with these contents in their classroom (André, 2019).

In this sense, Araújo *et al.* (2017, p. 2) state that:

The quality and relevance of the pedagogical practice offered by professors at universities have been a constant concern of researchers focused on educational problems. In this historical moment, teachers have generally maintained a teaching action based on assumptions of the conservative paradigm, which is strongly influenced by Newtonian-Cartesian thought, which privileges studying the parts without making articulations with the whole, separating without the concern of joining by re-articulated. Therefore, there is no relationship between the parts and the whole.

Given this prerogative, authors such as Pereira (2008) and Medeiros (2011) elucidate those submicroscopic concepts (such as those of Biochemistry) need to be understood, permeating the systemic and complex paradigms, considering an articulation of the parts for a better understanding of the whole and recognizing the interdependence of the macro and micro-universe. Therefore, an exclusively Cartesian perspective does not favor forming such complex concepts. However, teaching practice in higher education institutions is still aligned with a conservative perspective, while the moment we are experiencing calls these teachers "to align their practices according to the assumptions of the innovative paradigm, which seeks to train critical subjects who implement the spirit investigative and interpretive knowledge" (Araújo *et al.,* 2017, p. 2).

Thus, a teaching practice influenced by the Cartesian paradigm in which these contents of a systemic-complex nature are taught in a dissociated/fragmented and decontextualized way, without establishing relationships, will hardly allow a holistic view of the whole or will (hardly) contribute to overcoming these difficulties present in their teaching. According to Jofili, Sá, and Carneiro-Leão (2010), it is possible to observe students' difficulty in issues involving abstractions, failing to establish relationships between the microscopic universe and macroscopic organic functions.

In this context, it is necessary to seek alternative paths that enhance the teaching-learning process of biochemical concepts to guide specific actions for studying domain concepts that are poorly structured in their cognitive elaboration in an articulated and paradigmatic perspective. In this sense, Project-Based Learning (PBL) is configured as a methodological possibility that enables harnessing a paradigmatic base, as it invites the student to build biochemical concepts in a contextualized and articulated manner (Arantes do Amaral, 2018; Jespersen, 2018). PBL is a teaching model that uses real-world problems to articulate the specific formal content by inserting students in a situation in which they can identify themselves (Blumenfeld et al., 1991; Moursund, 1998; Howard, O'Hara and Sanborn, 1999; Draper, 2004; Ergül & Kargin, 2014; Bender, 2014; Garcês, Santos and Oliveira, 2018; Pascon et al., 2022).

The study by Garcês, Santos, and Oliveira (2018) discusses the application of the PBL methodology to work on metabolic biochemistry in the context of a Bachelor's degree in Natural Sciences with a specialization in Chemistry. The authors conclude that PBL proved to be an efficient strategy in teaching metabolic biochemistry, as it was able to unite the three dimensions for the development of competencies: the construction of knowledge (through the approach to content), the development of skills (teamwork, oral and written communication, use of digital tools) and the demonstration of attitudes (through awareness of problems present in society and the use of biochemistry in the prevention of metabolic diseases).

It is also emphasized in the literature that the implementation of PBL is associated with benefits regarding the development of skills and competencies, such as the promotion of interpersonal communication and teamwork skills (work environment management and results orientation) (Crespí; Garcia-Ramos; Queiruga-Dios, 2022); the development of collaboration and problem-solving skills (Pacheco et al., 2021); the development of skills that can be transferred to contexts other than academia (Melguizo-Garín et al., 2022); greater proximity in the interrelationship between students and teachers, as well as a broader understanding of the role of the teacher (Guajardo-Cuéllar; Vázquez; Gutiérrez, 2022); students come to understand the importance of developing skills related to teamwork (Melguizo-Garín et al., 2022).

Based on these foundations, the objective of the present study is to analyze the construction of concepts on Metabolic Integration from a biochemical and paradigmatic point of view through the application of Project-Based Learning (PBL).

Materials and methods

The study has a qualitative approach (Júnior & Batista, 2021) and is also configured as an Interventional Research (Teixeira & Megid Neto, 2017).

The social actors were 06 (six) students enrolled in a Biochemistry discipline, present in the curriculum of the Full Undergraduate Degree in Biological Sciences (Licenciatura) at a Public Institution of Higher Education located in Pernambuco (Brazil). Students agreed to participate in the study by signing the Informed Consent Form (ICF).

The 06 (six) undergraduates were part of the same workgroup, which was selected to compose this study through the following inclusion criteria: (1) Presence of members in all the action meetings; (2) Delivery of all collective productions; (3) Delivery of all individual productions; (4) Presentation of artifacts; and (5) Group unchanged throughout the actions.

The didactic-pedagogical planning was carried out following PBL (Behrens, 2013; Bender, 2014). A sequence of actions was elaborated to work the Metabolic Integration content in a problematic way, based on the anchor: "What would be much beyond weight concerning the problem of childhood obesity?" based on the display of an excerpt from the documentary "Much Beyond Weight.". Bender (2014) defines the anchor as the basis for asking and as having the purpose of grounding teaching in a real-world setting.

The action based on PBL was organized in ten moments and involved face-to-face and virtual mediation for constructing the projects. Conceptual deepening activities were made available throughout the ABP phases to link the specific formal content to the anchor. Students were evaluated through collective and individual productions regarding the concept construction in an articulated and contextualized way with childhood obesity. Performing such productions aligns with Behrens (2013), who points out ten phases for developing learning projects, with research and individual production being two of these phases.

The data that compose this study were obtained by collecting a document (individual production) using the Direct Documentation technique (Lakatos & Marconi, 2017). The individual production in question is an activity of conceptual deepening on the Metabolic Integration theme and was used as a documental resource in this work. This production was chosen because of its objective, which consisted of evaluating the formation of concepts on the subject.

The activity was structured into six questions: (1) Explain the interdependence of metabolic processes, considering the need, intake, and use of proteins, carbohydrates, and lipids; (2) Explain how the body establishes its energetic substrates after a meal; (3) How are metabolic energy substrate reserves mobilized in the fasting state?; (4) How are energy reserves restored in an initial re-feeding after a fasting period?; (5) Comment on the role of Acetyl-CoA in energy metabolism; and (6) Comment on the importance of allosteric and hormonal regulation for metabolic control in the context of enzymatic reactions.

The analysis of the students' productions was carried out based on the establishment of two types of analysis categories: 1) based on the paradigms of Science (Cartesian, Systemic and Complex) based on their characteristics in order to classify the students' responses, as well as, 2) from the creation of three categories to analyze the construction of biochemical concepts, which were elaborated from the students' production, namely: (C1) Articulation between childhood obesity and its influence on possible metabolic destinations of Acetyl-CoA; (C2) Relationship between allosteric and hormonal regulation and the development of childhood obesity and (C3) Conceptual gaps.

Results and discussion

Based on the analysis mechanisms of individual production presented in the methodology, Table 1 presents an overview of the construction of the six social actors participating in this study (conceptual deepening activity on Metabolic Integration).

The table was colored in order to facilitate understanding of the results, indicating the student's permeation in the conceptual deepening analysis categories represented by the initials C1, C2, and C3 (colored in different shades of purple) and in the Science paradigms (colored in different shades of blue), always from a lighter to a darker shade, illustrating the progression to more advanced stages; the dashed lines represent the flexibility to permeate different paradigms and the double arrows represent the constant transit between the Science paradigms. The column was left blank without reference to a given aspect. The paradigms are represented by the initials CA (Cartesian), SY (Systemic), and CO (Complex).

STUDENT Sn	CATEGORY			PARADIGM		
	C1	C2	C3	CA	SY	CO
S1						
S2						
S3						
S4						
S5						
S6						

Table 1: Overview of Individual Production (IP).

The six questions answered by the students were analyzed according to the established categories (C1, C2, C3), and we will highlight some excerpts corresponding to each category for each of the six graduate students (S1, S2, S3, S4, S5, S6), as well how they were analyzed in the light of the paradigms of Science to consider their characteristics according to Brayner-Lopes (2015), who states that the contents in the Cartesian paradigm are treated with a tendency to simplify, immediacy and the search for simple causality, reflecting on content and mere memorization; on the other hand, objects in the systemic paradigm are no longer the focus, but the articulations between them are valued so that the sum of the parts is greater than the whole; finally, knowledge of the parties and their interrelationships are valued in the complex paradigm, seeking to reintegrate what the compartmentalization of disciplines has fragmented and divided into separate specialties and which is practically incommunicable in many cases.

Each category will be discussed below in light of the theoretical framework adopted.

C1 – Link between childhood obesity and its influence on possible metabolic fates of Acetyl-CoA

Category C1 was established to assess how the **Childhood Obesity** anchor could facilitate understanding of biochemical processes involving carbohydrate and lipid metabolism and the relationships established between molecular events and cellular, physiological, and environmental processes. Therefore, we seek a context capable of establishing a link between Cartesian, systemic, and complex perspectives from developing a project in PBL based on a multifactorial pathology. We present some excerpts from the graduate students' responses analyzed in the light of C1 in Appendix.

The highlighted excerpts tend toward the Cartesian paradigm, which can be justified by the influence of the Newtonian-Cartesian paradigm. According to Mariotti (2000), this paradigm has simple causality, coherence, unidirectionality, objectivity, quantification, simplification, reactivity, utilitarianism, and immediacy as its main characteristics.

As the Cartesian perspective proves insufficient to understand the world, it tends to move between paradigms (Behrens, 2009). Hence, there is a growing acceptance of systemic and complex paradigms. One of the fundamental principles of systems thinking is the emphasis on the interrelationship between the parts, negating the Cartesian paradigm's importance. However, "complex thinking integrates multiple data and approach angles to the same problem" (Mariotti, 2008, p. 36). In this sense, PBL is inserted as a possibility to conduct the teaching and learning process permeating the systemic and complex paradigms, in addition to the Cartesian.

C2 – Relationship between allosteric and hormonal regulation and the development of childhood obesity

Category C2 was established to identify how undergraduates concatenated the processes involved in regulating energy metabolism with a multifactorial pathological process to conduct the construction process of biochemical meanings in addition to the physiological events commonly dealt with in Biochemistry disciplines. We present some excerpts from the undergraduate students' responses analyzed in the light of C2 in Appendix.

As we can see in the table, only three of the six undergraduates addressed what had been proposed in the question. This may be due to the conventional methodological predominance of biochemistry classes, in which content explanation is disjointed and decontextualized.

The highlighted section for S2 aligns with what Nelson and Cox (2014) claim, as, according to them, glucose, fatty acids, and amino acids enter the liver after a calorie-rich meal. Insulin is released in response to high blood glucose concentration, stimulating tissue sugar uptake. The glucose is exported to the brain for energy needs and part to fat and muscle tissue. Excess glucose in the liver is oxidized to Acetyl-CoA, which is used in synthesizing fatty acids exported as triacylglycerols in VLDL to adipose and muscle tissue. The NADPH required for lipid synthesis is obtained by oxidizing glucose in the pentose-phosphate pathway. Excess amino acids are converted to pyruvate and acetyl-CoA, which are also used for lipid synthesis.

The highlighted section for S3 shows key concepts for the fed/fast cycle, such as glucose, insulin, and glycogen, which are in line with Champe, Harvey, and Ferrier's (2009) claims.

Finally, S4 presented an answer in line with what Silverthorn (2017) states because, according to them, the easiest source of obtaining glucose from plasma glucose homeostasis is through the organism's glycogen stores, predominantly in the liver. He/she adds that "the liver glycogen can supply the demand for glucose for about 4 to 5 hours" (p. 706). According to Silverthorn (2017), glucose homeostasis is maintained through the catabolism of converting glycogen, proteins, and fats into intermediates that can produce glucose or ATP. Using proteins and fats for ATP synthesis saves plasma glucose for use by the brain.

Several authors (Brayner-Lopes, 2015; Andrade-Monteiro, Brayner-Lopes, and Carneiro-Leão, 2019) have shown that submicroscopic and procedural concepts, such as those of biochemistry, need to be understood beyond the Cartesian paradigm. Knowledge fragmentation, verticalization, and linearity associated with conservative teaching methodologies negatively impact the objective of building contextualized and articulated concepts. Thus, paradigms that value the interrelationship between the parts, such as the systemic (Capra, 2006) or the complex, understood as an embrace between the Cartesian and the systemic (Mariotti, 2008), value teaching practices supported by emerging methodologies, for example, PBL.

C3 – Conceptual gaps

We have identified the following conceptual gaps for the highlighted excerpts, represented in Appendix.

Considering the table, most gaps are due to traditional pedagogical practices based on the Cartesian paradigm, which limits students' perspectives about establishing dynamic links between the parts and the whole. Biology contents generally move between the micro and macro universes. Hence, an approach dedicated to studying all these organizational levels is necessary, and beyond that, the interdependent relations exist between them. In this sense, the PBL project enables the learner to seek to understand, apply, and use concepts in situations beyond the traditional practices commonly used in the classroom.

Pedagogical actions based on PBL can be alternatives to overcome the gaps and problems arising from adopting pedagogical practices based on the Cartesian paradigm. Regarding the teaching and learning process of Biochemistry, in addition to the nature of the concept (complex, poorly structured, and demanding excellent abstraction skills), undergraduate students often encounter difficulties arising from Basic Education. When they arrive at a Higher Education Institution with outdated knowledge, they also come across a series of concepts, nomenclatures, and metabolic pathways that are often presented to them decontextualized, disjointed, and fragmented.

Therefore, when they encounter active approaches and innovative forms of assessment, they are surprised and have difficulty contextualizing the concepts worked on in contextualized activities. That is, they have difficulty internalizing the concepts if worked on unconventionally and materializing them in a problematized way. Therefore, the PBL methodology, which envisions the planning and application of exploratory theoretical classes based on the didactic transposition of the program content, can be a way to overcome such obstacles, especially in constructing biochemical concepts. As demonstrated in the study in question, based on the aforementioned methodology, the students mobilized the biochemical concepts to relate the macro universe of the context presented to the metabolic processes.

Conclusion

In this study, we have sought to evaluate ways and possibilities for building biochemical concepts related to integrated energy metabolism from a pedagogical action based on Project-Based Learning (PBL) in a contextualized and paradigmatic way. As we discovered in the study, most undergraduate students adequately used biochemical concepts relating childhood obesity with metabolic processes. The students applied biochemical concepts in their productions. They articulated the macro universe of the context presented to metabolic processes and recognized the physiological consequences of inadequate food intake.

Contextualization was considered throughout the teaching-learning process, from the presentation of the anchor to link the specific formal content to a context that could be identified by the students, as well as in the conduction of classes, preparation of activities, and proposition of artifacts in PBL. Furthermore, the documentary proved suitable for contextualizing the classes because it allowed the articulation of a multifactorial pathology – childhood obesity – with aspects of the macro and microscopic contexts, favoring discussions on Cellular and Metabolic Biochemistry throughout the entire discipline.

Therefore, the analysis here allows us to infer that the pedagogical action conducted through the PBL methodology enabled a contextualized conceptual approach based on an emerging paradigm. In addition, it configured a facilitating proposal in building concepts that demand a high degree of abstraction as they involve molecular structures and processes because the contextual development is systemic-complex. Thus, students were guided towards a conceptual (re)elaboration in an articulated and paradigmatic way.

References

Andrade-Monteiro A S F, Brayner-Lopes F M, Carneiro-Leão A M A (2019) Mobilizando os saberes docentes: Rumo à compreensão dos processos biológicos em uma perspectiva sistêmico-complexa. *Revista Ensaio*, 21, 10426.

André W D S (2019) *Elaboração, aplicação e validação de uma sequência didática à luz do Modelo das Múltiplas Perspectivas Pernambuco (MoMup-PE) para a construção de conceitos bioquímicos.* Graduação em Ciências Biológicas – Universidade Federal Rural de Pernambuco, Recife.

Arantes do Amaral J A (2018) Reflections on thirteen years directing community-based learning projects. *Collaborations: A Journal of Community-Based Research and Practice*, 2 (1), 2, 1-25.

Araújo R V S. *et al*. (2017) Situação prática para o estudo da Bioquímica dos alimentos por meio de uma produção coletiva na perspectiva de um paradigma inovador. *In:* Encontro Nacional de Pesquisa em educação em ciências (ENPEC), 11, Florianópolis. *Anais [...]*. Belo Horizonte: ABRAPEC.

Behrens M A (2009) *O paradigma emergente e a prática pedagógica*. 3. ed. São Paulo: Vozes.

Behrens M A (2013) *O paradigma emergente e a prática pedagógica.* 6. ed. Rio de Janeiro: Vozes.

Bender W (2014) *Aprendizagem baseada em projetos:* educação diferenciada para o século XXI. Porto Alegre: Penso.

Blumenfeld P C, Soloway E, Marx R W, Krajcik J S, Guzdial M, Palincsar A (1991). Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning. *Educational Psychologist*, 26, 3-4, 369–398.

Brayner-Lopes F M (2015) *Formação de docentes universitários: num complexo de interações paradigmáticas.* 260 f. Tese Universidade Federal Rural de Pernambuco, Recife.

Capra F (2006) *O ponto de mutação*. 35. ed. São Paulo: Cultrix.

Champe P C, Harvey R A, Ferrier D R (2009) *Bioquímica ilustrada.* 5. ed. Porto Alegre: ArtMed.

Crespi, P, Garcia-Ramos J M, Queiruga-Dios M (2022). Project-Based Learning (PBL) and Its Impact on the Development of Interpersonal Competences in Higher Education. *Journal of New Approaches in Educational Research*, 11, 2, 259–276.

Draper A J (2004). Integrating Project-Based Service-Learning into an Advanced Environmental Chemistry Course. *Journal of Chemical Education*, 81, 2, 221–224.

Ergül R N, Kargin E K (2014). The Effect of Project-based Learning on Students' Science Success. *Procedia - Social and Behavioral Sciences*, 136, 537-541.

Filatro A, Cavalcanti C C (2018) *Metodologias inov-ativas na educação presencial, a distância e corporativa.* 1. ed. São Paulo: Saraiva.

Garcês BP, Santos K O, Oliveira C A (2018). Project-based learning in the teaching of metabolic biochemistry. *Revista Ibero-Americana de Estudos em Educação*, Araraquara, 13, esp1, 526-533.

Guajardo-Cuéllar A, Vázquez C R, Gutiérrez M N (2022) Developing Competencies in a Mechanism Course Using a Project-Based Learning Methodology in a Multidisciplinary Environment. *Education Sciences*, 12, 3.

Howard M, O'Hara P B, Sanborn J A (1999). Pesticides in Drinking Water: Project-Based Learning within the Introductory Chemistry Curriculum. *Journal of Chemical Education*, 76, 12, 1673–1677.

Jespersen L M B (2018). Problem orientation in art and technology. *Journal of Problem Based Learning in Higher Education*, 6, 1, 1-14.

Jofili Z, Sá R G B, Carneiro-Leão A M DOS A (2010) A via glicolítica: Investigando a formação de conceitos abstratos no ensino da Biologia. *In:* Congresso ibero-americano de educação em ciências experimentais, 3, 4, 5. *Anais […].* São Paulo: Revista da SBEnBio.

Júnior C A O M, Batista M C (2021) *Metodologia da pesquisa em educação e ensino de Ciências.* Paraná: Massoni.

Lakatos E M, Marconi M A (2017) *Fundamentos da Metodologia Científica*. ed. 8, São Paulo: Atlas.

Mariotti H (2000) *As paixões do ego:* Complexidade, política e solidariedade. 3. ed. São Paulo: Palas Athena.

Mariotti H (2008) *As paixões do ego:* Complexidade, política e solidariedade. 3. ed. São Paulo: Palas Athena.

Medeiros E P (2011) *Formação do conceito sistêmico de respiração: um estudo articulando fenômenos macro e microscópicos.* 180 f. Mestrado em Ensino das Ciências Universidade Federal Rural de Pernambuco, Recife.

Melguizo-Garín A, Ruiz-Rodríguez I, Peláez-Fernández M A, Salas-Rodríguez J, Serrano-Ibánez E R (2022) Relationship Between Group Work Competencies and Satisfaction With Project-Based Learning Among University Students. *Front Psychol*, 9, 13.

Moursund D (1998). Project-based learning in an information technology environment. *Learning and Leading with Technology*, 25, 8, 4–5.

Nelson D L, Cox M M (2014) *Princípios de Bioquímica de Lehninger.* 6. ed. Porto Alegre: Artmed.

Pacheco M A P, Florez D G, Aguado C M O, Solano H L (2021). Does project-based learning work in different local contexts? A Colombian Caribbean case study. *Educational Review*, 73. 6, 733-752.

Pasco, D M, Vaz D R, Peres H H C, Leonello V M (2022). Project-based learning in remote teaching for undergraduate nursing students. *Revista da Escola de Enfermagem da USP,* 56, e20220058.

Pereira A F (2008) *Diagnóstico inicial das dificuldades de articulação e sobreposição dos conceitos básicos da genética utilizando jogos didáticos.* 189 f. Mestrado em Ensino das Ciências Universidade Federal Rural de Pernambuco, Recife.

Sá R G B (2007) *Um estudo sobre a evolução conceitual de respiração*. 161 f. Mestrado em Ensino das Ciências Universidade Federal Rural de Pernambuco, Recife.

Silverthorn D U (2017) *Fisiologia Humana:* Uma abordagem integrada. 2. ed. Porto Alegre: Artmed.

Teixeira P M M, Megid Neto J (2017) Uma proposta de tipologia para pesquisas de natureza interventiva. *Ciênc. Educ.,* Bauru, 23, 4, 1055-1076.

Appendix: Excerpts from Individual Productions for analysis.

Excerpt selected for analysis in C1		**Paradigm analysis**
S1	*""In aerobic glycolysis, there is the conversion of pyruvate to Acetyl-CoA, and the latter provides Malonyl-CoA formation, which in turn regulates the synthesis of fatty acids. Dietary carbohydrates are the main source of carbon for forming triacylglycerol deposition in humans and it can therefore be explained why excess blood glucose increases the formation of adipose tissue".*	Predominance of the **complex** paradigm from the articulation that emerges from the union between the knowledge of the parts (**Cartesian**) and the interrelationships between the parts with the whole (**systemic**), by linking biochemical processes to a possible cause of obesity.
S2	*"Acetyl-CoA is a common metabolic intermediate in the aerobic energy metabolism of carbohydrates, proteins. This means that these substances can only be used in mitochondria as an energy source after being transformed into Acetyl-CoA".*	The **Cartesian** paradigm prevailed when describing a vertical knowledge and deepening the parts without articulation.
S3	*"The main function of coenzyme A in metabolism is to be a receptor for the Acetyl group. The synthesis of Acetyl-CoA is the "link" connecting the glycolytic pathways, beta-oxidation and protein degradation in the Krebs cycle. Coenzyme-A receives acetyl groups coming from the oxidation of glucose, lipids and some amino acids (isoleucine, leucine, lysine, phenylalanine, threonine, tryptophan and tyrosine). Normally we can find coenzyme A both inside and outside the mitochondria, but the basic functions of Acetyl-CoA are different: Cytosolic Acetyl-CoA has the basic function of lipid biosynthesis and intra-mitochondrial Acetyl-CoA has a basic function of oxidation of the Acetyl group".*	He/she permeated the **systemic** paradigm. He/she coherently articulated the union between the in-depth knowledge of the parts (**Cartesian**) and the interrelationships between the parts and the whole (**systemic**). He/she presents elements of linearity and of the interrelationships of the parts with the whole.
S4	*"Acetyl-CoA is oxidized to CO_2, the formation of Acetyl-CoA starts the Krebs cycle in the mitochondria matrix. It will integrate a cellular oxidation chain, meaning a sequence of reactions in order to oxidize carbons, turning them into CO_2, and capture energy when ATP synthesis is coupled to the electron transport chain".*	He/she permeated the **Cartesian** paradigm by verticalizing knowledge, making reference to elements of the microuniverse without articulating them to macro-universe processes.
S5	*"Acetyl-CoA is oxidized to CO_2, and in the matrix of mitochondria the Krebs cycle begins with the formation of Acetyl-CoA. And so, it will integrate a cellular oxidation chain with the purpose of oxidizing the carbons, transforming them into CO_2, and capturing energy when ATP synthesis is coupled to the electron transport chain".*	They permeated the **Cartesian** paradigm, as they exposed linear, linked and vertical knowledge, making in-depth reference to metabolic processes, but without presenting articulations.
S6	*"Acetyl-CoA is a key intermediate in cell metabolism. In this perspective, Acetyl-CoA is the result of the total oxidation of organic molecules such as pyruvate, fatty acids and amino acids, meaning that regardless of the biomolecule used*	

	to obtain energy, the end will result in Acetyl-CoA formation. The transformation of pyruvate, which is found in the cytosol, into Acetyl-CoA takes place in the mitochondria. The process which transforms pyruvate into Acetyl-CoA is called Oxidative Decarboxylation, in which a carboxyl group is removed and released as CO_2. Acetyl-CoA participates as an intermediary in the Krebs cycle, as it forms citrate when it condenses to oxaloacetate. It is in this cycle that Acetyl-CoA will be fully oxidized to CO_2, parallel to the production of reduced coenzymes. This molecule is found in synthesis pathways as well, since it is the main fat-forming molecule in lipogenesis".	
	Excerpt selected for analysis in C2	**Paradigm analysis**
S1	Did not consider the approach proposed in the question.	
S2	*"Our body has a high level of glucose right after a full meal of carbohydrates, lipids and proteins. This process stimulates the pancreas to secrete insulin, which stimulates the cells to absorb glucose, while the excess will be stored as glycogen in the liver".*	Tendency to simplification and immediacy, thus permeating the **Cartesian** paradigm**.**
S3	*"Our body has a high level of glucose right after a full meal of carbohydrates, lipids and proteins, stimulating the pancreas to secrete insulin. Acting through receptors on the plasma membrane, insulin stimulates glucose uptake by muscles and adipose tissue, where the glucose is converted to glucose-6-phosphate. Insulin also activates glycogen synthase and inactivates glycogen phosphorylase in the liver, so much of the glucose-6-phosphate is channeled to form glycogen".*	Although mention is made of a macro-universe process (meal), the micro-universe processes are presented in a linear, objective and generalized manner, without articulating the processes, thus permeating the **Cartesian** paradigm.
S4	*"Our organism needs energy from the oxidation of organic molecules in order to carry out daily activities - an example being our main energy source, which is glucose. However, when the individual is fed beyond caloric needs, the store is directed to biosynthesize fatty acids with the help of the hormone insulin (hypoglycemic), therefore, all this excess is transformed into adipose tissue. When there are hormonal changes, there is a predisposition to obesity, considering that acting on the increase of hunger, instead of satiety (leptin and adiponectin), they engage another process".*	He/she permeated the **systemic** paradigm, as they related a macroscopic (food) to microscopic (metabolic pathway and hormonal changes) aspect, presenting a network of relationships in their reasoning, emphasizing the dialogic construction between the aspects of the macro and microuniverse, making procedural mention of the events of interaction between organism/environment and organism/organism.
S5 **S6**	Did not consider the approach proposed in the question.	

Student (Sn)	**C3 Conceptual gaps**

S1	Lack of correlation between allosteric and hormonal regulation with the development of childhood obesity.
S2	Disarticulated knowledge in the highlighted fragment in category 1.
S3	Lack of correlation between childhood obesity and microscopic and molecular aspects; In his/her activity, he/she mentions microscopic aspects without linking them to the individual and the environment.
S4	Lack of articulation between elements from the micro-universe to the macro-universe.
S5	Verticalized knowledge; Lack of correlation between allosteric and hormonal regulation with the development of childhood obesity.