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Meaningful Learning and Mathematical Modelling - Contributions to Dealing with Business Problem Situations in Higher Education

Arrigo Fontana[a]
Cláudia Lisete Oliveira Groenwald[a]

[a] Universidade Luterana do Brasil – ULBRA, Programa de Pós-Graduação em Ensino de Ciências e Matemática – PPGECIM, Canoas, RS, Brasil

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ABSTRACT

Background: Applying mathematical modelling in problem situations shows the possibility of observation of the existing meaningful learning as a learning environment for the construction of knowledge with problems situations of the professional daily life of students enrolled in the subject Operational Research of Fisul College Administration Course, at Serra Gaúcha, Rio Grande do Sul. **Objectives:** To elaborate, construct, and study a mathematical model that describes and/or explains these living situations in a professional routine integrated into the meaningful learning theory. **Design:** Qualitative research, based on the meaningful learning theory, in the operational research with the assistance of *Solver* and mathematical modelling. **Setting and participants:** The research was carried out in two classes of 24 students who attended the subject Operational Research in Higher Education. **Data collection and analysis:** The research was developed in five stages: Diagnostic Probing, Advanced Organizers, Evaluative Instrument, Modelling of Operational Research Problems, and Closure Activities. **Results:** Most students have evidence of the presence of subsumers in the activities developed, inserting concepts related to management, where they are related to the Business Administration course. **Conclusions:** The results revealed evidence of the Administrator's professional conditions, such as the ability to recognise and define problems, introduce changes in the productive process, where the problems originated, and traces of the construction of knowledge itself were perceived.

Keywords: Knowledge and learning; Mathematical modelling; Meaningful learning; Operational research.

Corresponding author: Arrigo Fontana. Email: arrigo.fontana@fisul.edu.br

Aprendizagem significativa e a modelagem matemática - Contribuições para o enfrentamento de situações problemas empresariais no ensino superior

RESUMO

Contexto: A aplicação de modelagem matemática em situações-problema, mostra a possibilidade de observação da existência da Aprendizagem Significativa, como um ambiente de aprendizagem para a construção do conhecimento com situações problemáticas do cotidiano profissional de estudantes matriculados na disciplina de Pesquisa Operacional do Curso de Administração da Faculdade Fisul, da Serra Gaúcha do Rio Grande do Sul. **Objetivos**: Objetivo principal a elaboração, a construção e o estudo de um modelo matemático que descreva e/ou explique essas situações vivenciadas no dia a dia profissional, integrados a teoria da Aprendizagem Significativa. **Design:** A metodologia utilizada nesta pesquisa foi de cunho qualitativo, onde o estudo foi embasado na teoria da aprendizagem significativa, na pesquisa operacional com a aplicação da ferramenta *Solver* e na modelagem matemática. **Ambiente e participantes:** A pesquisa foi realizada em duas turmas de 24 estudantes que frequentaram a disciplina de Pesquisa Operacional do Ensino Superior. **Coleta e análise de dados**: Foram aplicadas cinco etapas: Sondagem Diagnóstica, Organizadores Avançados, Instrumento Avaliativo, Modelagem de Problemas de Pesquisa Operacional e Atividade de Fechamento. **Resultados:** A maioria dos estudantes possui evidências da presença de subsunçores nas atividades desenvolvidas, inserindo conceitos relacionados a gestão, onde tem relação com o curso de Administração. **Conclusões:** Assim, nos resultados foi possível observar algumas evidências em relação as condições profissionais do administrador, como a capacidade de reconhecer e de definir problemas, introduzir alterações no processo produtivo, onde se originaram os problemas e foram percebidos vestígios de construção do próprio conhecimento.

Palavras-chave: Ensino e aprendizagem; Modelagem matemática; Aprendizagem significativa; Pesquisa operacional.

INTRODUCTION

The fundamental task of the school and the teacher is the development of logical reasoning skills, critical thinking, and creativity, supported not only by reflecting on the knowledge acquired by the science in question but also on its applications to technology and social progress (Santos, França & Santos, 2013). In this sense, humankind has developed mathematics according to their needs for survival in the social environment, in particular, for solving problem situations of professional life and rebuilding knowledge in everyday life.

We chose to develop operational research concepts in the Business Administration course at Fisul College, intertwined with the methodology of mathematical modelling and meaningful learning, carrying out an experiment that would allow the discussion, analysis, and resolution of problem situations in these students' professional life.

The general objective was to investigate the contributions to the teaching and learning process of an articulation between the theory of meaningful learning and mathematical modelling in the context of the development of mathematical models by Business Administration students attending the subject Operational Research.

According to a concept aimed at teaching critical mathematical learning and its probabilities as a mathematics learning environment, meaningful learning, operational research, and mathematical modelling are the union of this work, which also addresses the relationships between technology, modelling, and work with mathematical content, more specifically, as a possibility of building and analysing models that make it possible to approach the specific theme of each undergraduate, in a computerised environment, in higher education. We believe that this approach is a tool that helps students to solve, better understand, and take a critical stand before problem situations and obstacles arise from their experience in academic life and beyond.

MEANINGFUL LEARNING AND THE CONSTRUCTION OF KNOWLEDGE

Meaningful learning is a process that involves the interaction of new information with a specific knowledge structure, defined as a subsumer, existing in the individual's cognitive structure (Moreira, 2011a). It is from this point of support that the learning of new concepts must take place or, as summarised by Moreira (2006, p. 38): "Meaningful learning is the process through which new information acquires meaning through interaction (not association) with preexisting relevant aspects in the cognitive structure".

Ausubel (1963, p. 58) understands meaningful learning as "the human mechanism par excellence to acquire and store the vast amount of ideas and information represented in any field of knowledge". Moreira (2011b, p. 36) states that "individuals learn meaningfully when they can relate, in a substantive (non-literal) and non-arbitrary way, the new information with a specific knowledge structure that is an integral part of their previous cognitive structure".

According to Moreira (2011, p. 40), subsumers are "clear, stable, differentiated, specifically relevant concepts or propositions –in the cognitive structure", also called prior knowledge or anchor ideas. These subsumers serve to anchor new knowledge. Moreira (2011, p. 26) recognises that:

> Prior knowledge is an ideational and organisational matrix for incorporating, understanding and fixing new knowledge when it is "anchored" in specifically relevant knowledge (subsumers) preexisting in the cognitive structure. New ideas, concepts, and propositions can be meaningfully learned (and retained) so that other specifically relevant and inclusive ideas, concepts, and propositions are adequately clear and available in the subject's cognitive structure and function as "anchor" points to the first ones. (Moreira, 2011b, p. 26)

When meaningful learning is not effective, the student uses mechanical learning, i.e., they "memorise" the content, which, not being significant to them, is stored in isolation, and may even be forgotten afterwards, according to Ausubel's theory (1976). So, students forget everything after completing tests, including what they were taught. We can observe that some are unwilling to learn in a "mechanical" way; therefore, they do not learn at all. These students fail even more than once in the same school year. It is essential, even more so in these cases, to use strategies that include meaningful learning opportunities. Rote learning leads many students and teachers to believe that teaching has been effective. When the student manages to reproduce the content in the assessments as transmitted by the teacher, there is this belief that there has been learning. In this context, many approvals for the next series happen without actual learning.

As has already been presented in some studies, learning to teach is linked to understanding, logical reasoning, and reflection. Reflection should occur where there is mutual participation as a tool for cooperation and understanding, thus developing activities to instigate student cognitive support. For knowledge elaboration, students play a very important role because, for the process to occur, the teacher must be a challenging agent.

The educators' challenge is to discover and awaken reasons for learning, making classes attractive for teenagers, working on relevant content that allows sharing with other experiences (besides school) and making the classroom a highly stimulating environment for learning, building real confluence with actual learning.

According to Rios (2010), this line of studies is accentuated as, through the teaching gesture, the teacher shows students how important it is to understand the content. In a mediation exercise, they create an encounter with reality, considering their already existing knowledge and seeking to articulate it with new knowledge and practices.

Alro and Skovsmose (2010) emphasise that, although learning is an individual experience, it happens in social contexts soaked in interpersonal relationships and warn that the quality of communication in the school context directly interferes with learning. To them, there is no relationship of domination in a dialogue, as it is unpredictable. Teachers and students act together, analysing their other participants' perspectives in the dialogue.

The authors emphasise that dialogue is characterised by eight acts of communication:

- Make contact – create rapport between participants by listening to each other's perspectives in a climate of trust;
- Perceiving perspectives – the process of examining possibilities and creating hypotheses. Some lines: What else do you know about it? What is this? Explain better... ;
- Recognise – recognise a perspective to explain what they are doing;
- Take a stand – say what you think with a receptiveness to criticism regarding your position. Rejecting their ideas without argument denotes insecurity;
- Think aloud – make the thought public. Hypothetical questions may arise;
- Reformulate – paraphrase, clarifying the argumentative process;
- Challenge – the challenge is successful when the participants understand it;
- Assess – constructive feedback.

According to Rihs and Almeida (2017), in the current context of the world in a constant transformation of information technology, the teacher must have their lesson planning so that learning is provoked, taking into account that the important thing is to elaborate questions that instigate the individual to experience the search and verify the several possible answers.

To give meaning to what is being taught, it is necessary to organise "activities with which the student can generalise, differentiate, abstract, and symbolise the concepts worked on" (Anastasiou, 2006, p. 22). The meaningful learning theory (Ausubel, 1980) proposes to explain the learning process that occurs in the human mind through the organisation and integration of the material in the cognitive structure [1]. For Ausubel: "Meaningful learning involves a selective interaction between the new learning material and the preexisting ideas in the cognitive structure" (Ausubel, 2003, p. 3), allowing anchoring. This term suggests connecting preexisting ideas with new ones over time. We then understand that "in the process of subsumption, preexisting subordinating ideas provide anchorage for meaningful learning of new information". Moreira and Masini (1982) state that in the operation of meaningful learning, the new sapience interacts with a specific knowledge structure that Ausubel defines as existing subsumers in the individual's cognitive structure. Therefore, the links that need to be established between information must not be shared for learning to be meaningful. Ausubel (2003) states that it is complex and depends on preexisting elements in the cognitive structure.

According to Ausubel (1973, p. 25), a subsumer is a structure in which new information can be added to the human brain, which is highly organised and holds a conceptual hierarchy that stores the subject's previous experiences. In Physics subject, for example, if the concepts of measurement units already exist in the student's cognitive structure, these will serve as subsumers for new information regarding the concepts of velocity and acceleration.

In the absence of subsumers, the use of advanced organisers is suggested. Advanced organisers are pedagogical mechanisms that help connect what learners already know and what they will acquire, says Ribeiro (2011). In this case, the advanced organiser plays the role of mediator, changing preexisting ideas and preparing them for the study of later material: "The organisers are at a higher level of abstraction, generality, and inclusiveness than the new materials to be learned " (Ausubel, 2003, p. 11).

The use of advanced organisers is justified because the prior knowledge existing in the learner's cognitive structure is insufficient to establish a relationship with the new knowledge proposed by the instructional material.

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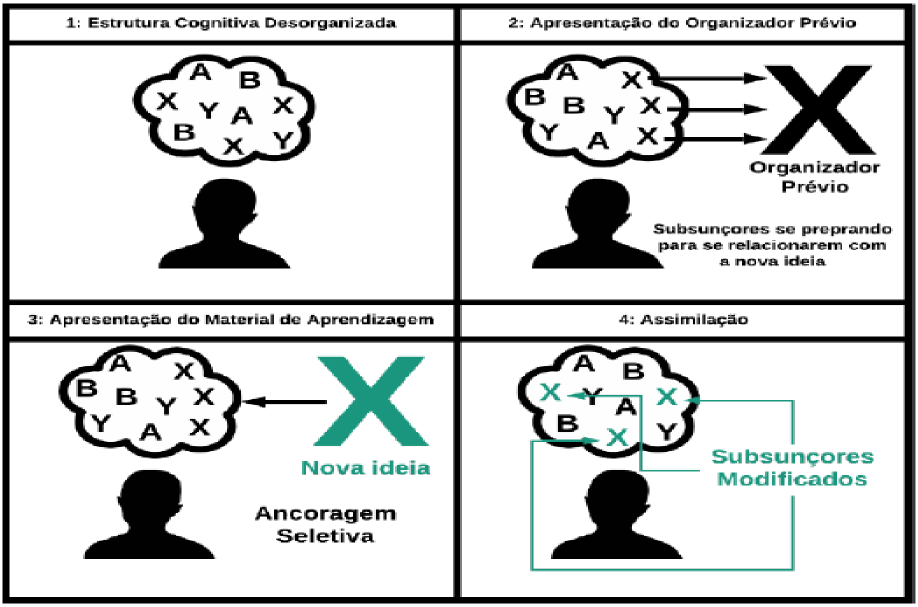
[1] Cognitive structure is the result of the processes by which knowledge is acquired and used.

Then, the advanced organiser modifies the previous knowledge, enabling them to receive the new knowledge. Figure 1 presents an illustration representing the basic functioning of an advanced organiser.

Figure 1

Representation of the operation of an advanced organiser. (Adapted from Ribeiro, 2011).



The organisers mentioned in the context can also activate the subsumers students were not using. However, they are present in their cognitive structure. According to Moreira and Masini (2006), advanced organisers can be in the form of texts, films, schemes, drawings, photos, questions, and conceptual maps, among others. They are presented to the student at a broader level, allowing the integration of the new concepts learned, which makes it easier to relate new information to the existing cognitive structure.

Moreira (2006) says that when introducing a new concept, one should take advantage of the subsumers that anchor it with the use of concepts and propositions on these themes. According to Moreira (1999), the student may have subsumers, and these are not active in their cognitive structure. In this context, the teacher must develop work with advanced organisers to prepare and/or activate the existing knowledge in students' cognitive structures.

The teaching resources used by the teacher should aim at associating the new material with what was previously presented through references and comparisons present in activities that demand the use of knowledge in a new way. This is a way to speed up the subsumption process, according to Moreira and Masini (2006).

Ausubel, Novak, and Haniensem (1980, p. 42) warn that meaningful learning "should not be interpreted simply as learning meaningful material"; materials are potentially meaningful if they have meaning. That is, the acquisition of new meanings is completed by definition, even before any attempt at learning. Under this view, the teacher should lead students to identify the relevant content in the cognitive structure, explaining the importance of this content for learning the new material. Ausubel, Novak, and Haniensem (1980, p. 42) complement the above, stressing that the content needs to contain important relationships to offer an overview of the material at a higher level of abstraction and provide inclusive organisational elements that highlight the specific content of the new material.

The previous knowledge is fundamental in the construction of knowledge and in elaborating the relationships between concepts because when students are presented with new content, they use their concepts, conceptions and representations acquired during previous experiences as a reading and interpretation instrument of the new material. Thus, it is notably important for the teacher who seeks a teaching that provides meaningful learning to represent the conceptual and propositional structure of what they intend to teach, thus consolidating the students' prior knowledge. From this point on, the teaching process begins (Moreira, 2006).

Problem solving is the way the teacher can explore students' prior knowledge from problem situations. Ausubel et al. (1980) state that problem solving represents a form of activity or directed thinking in which both the cognitive representation of previous experience and the components of the problem situation are reorganised to ensure a certain objective in a teaching and learning process. Solving a problem situation can be pointed out as a means to promote such learning. Ausubel (2003) conceives that the insight comes from a process of progressive clarification on means-ends relationships based on the formulation, verification, and rejection of alternative hypotheses.

The school, as a social environment that proposes resignifying learning, identifies what students have in terms of knowledge and different ways to enhance them.

Motivation, self-control, affectivity, and exploration of prior knowledge stand out, among others, as meaningful, influential learning elements. Meaningful learning means that the students must see themselves as organs of the process and crave to delve into the content they intend to learn, establishing relationships between this and the knowledge they already have.

For learning to occur meaningfully, people must relate knowledge as the existence of a minimum content in their cognitive structure, surrounded by sufficient subsumers to meet the related needs and materials to be assimilated with significant potential.

In short, directing this theory to the research that will be developed on abilities and skills, based on the concepts of Ausubel's meaningful learning theory at the higher education level, the Business Administration students may have already developed professional experiences related to decision-making. They may have already used their ability to observe, understand, and analyse the complexity of the organisation in which they operate, to understand the interrelationships between the different sectors of the company, and transfer knowledge from everyday life to the work environment.

In this research, we intended to relate Ausubel's meaningful learning to mathematical modelling, analysing mathematical modelling in the form of student learning so that it can be observed that it is absorbed, not arbitrarily, but by understanding.

One of the instruments that students can use to organise the teaching and learning processes is the construction of conceptual maps. Concept maps help students establish meaningful relationships between what they already know and need to understand, functioning as a learning method. Ausubel's theory for the development of conceptual maps cites three basic ideas. The first conceives the addition of new learning as constructions based on relevant concepts and propositions already present in the subject's knowledge structure. The second sees cognitive structure as a hierarchical organisation, with broader, more inclusive concepts occupying higher levels in the hierarchy and more specific, more or less inclusive concepts embodied by more general concepts. And in the third moment, when meaningful learning occurs, the relationships between concepts become more explicit, more precise, and better integrated with other concepts and propositions (Novak, Cañas, 2006).

MATHEMATICAL MODELLING AND THE CONSTRUCTION OF KNOWLEDGE

According to Bassanezi (2002), mathematical modelling seeks to investigate everyday problem situations whose objective is the construction or knowledge of a mathematical model that describes the real-life situation for decision-making. It also seeks to know the basic concepts involved in the process of mathematical modelling in the context in which they are inserted.

Mathematical modelling is usually associated with two components: the problem arising from a real-world phenomenon and the mathematical model, i.e., the mathematical structure used to represent this phenomenon. The modelling activity occurs when a mathematical approach is employed so that the mathematical model answers the problem in question.

Mathematical models are of great importance for science and engineering in general, especially since the moment when the digital computer significantly simplified the task of calculation. In this sense, technological resources (computers, tablets, cell phones, etc.) are or should be included in the teaching and learning process, discussing which resources are important for the development of education.

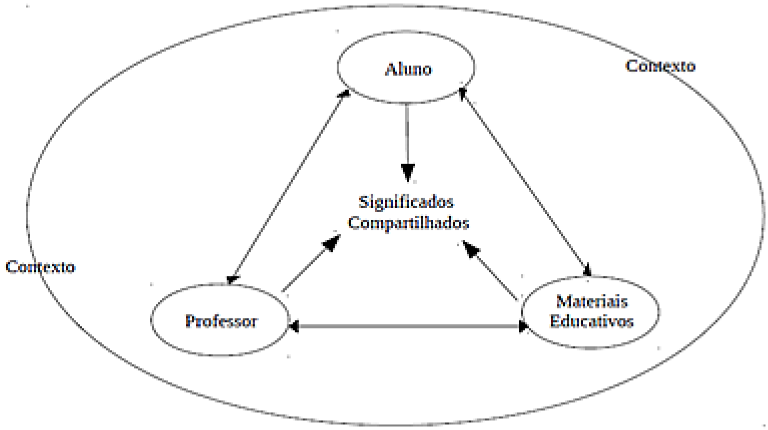
Borssoi (2017, p. 143) states, "numerous studies indicate that teaching and learning environments should not be dissociated from information and communication technologies, as these can promote positive learning experiences". The use of technology during the teaching and learning process considers the human mind similar to a computational system, capable of receiving information from the sensory system and processing it, internally representing the external world.

In this context, mathematical modelling can be a strategy to help in meaningful learning because, in general, it addresses real problems, leading the students to investigate, transforming them into a mathematical problem, and participating in the learning itself, which, according to "modelling, consists of the art of transforming real-life problems into mathematical problems and solving them, interpreting their solutions in the language of the real world" (Bassanezi, 2002, p. 16).

According to Moreira (2011a), the triadic relationship proposed by D. Bob Gowin in the 1980s, where knowledge is built from the interaction between teacher, students, and educational materials, must become quadric, where there would be not only the interaction between the three elements mentioned above but there would also be interaction with the computer, currently, with technology, as shown in Figure 2.

Figure 2

Meaningful learning in Gowin's social interactionist view, 1981. (Moreira, 2011a, p. 163).



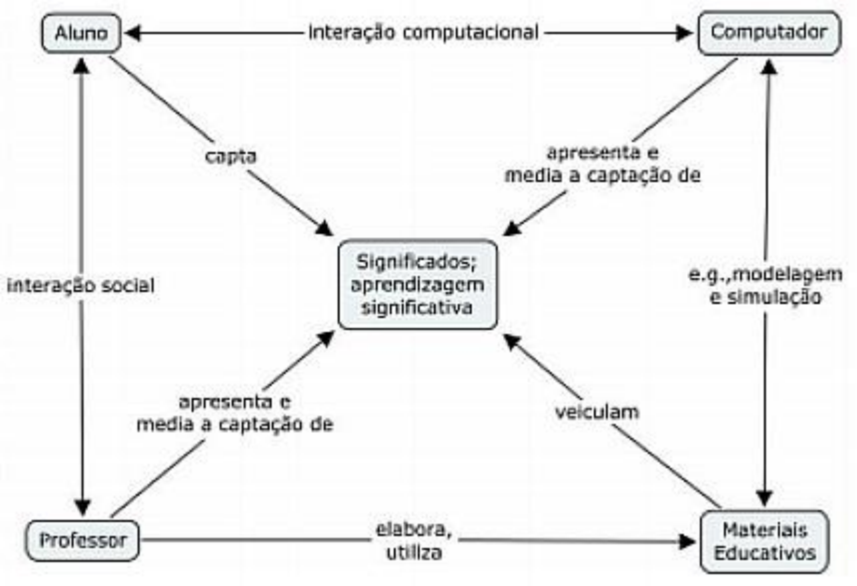
According to Figure 3, there is a new scenario, which represents the model of interrelation between the educational material, teacher and students, exposes and mediates the meanings so that meaningful learning is possible, complemented by the use of technology, understood as the computer.

Offering supplementary resources, such as technology, is one of the ways to guide students towards a teaching and learning process in which they feel co-responsible for building knowledge. Allowing different representations for a mathematical object, among other potentialities, is what this process has to offer.

According to Diniz and Borba (2012), to better represent a problem situation, simulation and prediction can be used to find new values that are inserted in the context. Thus, toLévy (2000, p. 166), simulation enables the ability to easily vary the parameters of a model, and immediately and visually observe the consequences of this variation constitutes a genuine expansion of the imagination.

Figure 3

Meaningful learning (capturing meanings) in a computational vision.
(Moreira, 2011a, p. 172).



To Zanato, Strieder, and Campos (2020), from this perspective, using technologies in the teaching and learning process means enriching, interacting, and building knowledge.

When the teacher is faced with investigation scenarios, they may concentrate on a risk zone[2]. As identified by Borba and Villareal (2005), doubts must be faced, and subsequently, technologies, especially computers, must be used to reorganise thought. However, technology challenges teachers' authority, making them leave their comfort zone and allowing the student to have rich experiments compared to activities with pencil and paper in a

[2] Risk zone is a concept proposed by Penteado (2004, apud Skovsmose, 2008, p. 35), which refers to the fact that teachers cannot foresee all the events in the classroom, being subject to unexpected questions for which they may not have ready answers.

relatively short time. It also enables algebraic, numerical, and graphic forms of representation, adapting to the different particularities of learning.

According to Barbosa (2001), “Mathematical modelling is a learning environment where students are invited to problematise and investigate, through mathematics, problem situations with reference to reality, that is, experienced problems”. When the teacher brings the students into his/her reality, the systematisation of the content becomes easier to be interpreted and understood, making it easier for students to find the solution to a specific problem of their reality.

The authors Barbosa (2001), Burak, and Aragão (2012) also say that mathematical modelling is a means of breaking with ready-made models of teaching mathematics and allowing students to actively participate in their teaching and learning process, relating mathematical knowledge with their daily lives and acquiring meaningful learning.

OPERATIONAL RESEARCH AND THE CONSTRUCTION OF KNOWLEDGE

In Brazil, operational research began in the 1960s. According to Arenales et al. (2007, p. 3):

> The first Brazilian Operational Research Symposium was held in 1968 at ITA, in São José dos Campos, São Paulo. Then, SOBRAPO (Sociedade Brasileira de Pesquisa Operacional) was founded. It has published the first operational research scientific journal in over 25 years. The book *25 Anos de Pesquisa Operacional no Brasil* (25 Years of Operational Research in Brazil), a commemorative edition of SOBRAPO’s Silver Jubilee, launched in 1993, contains reports on the history of operational research and pioneering researchers in the country[3].

To the authors Bilinski and Fernandes (2016), operational research is said to be a study that triggers processes, suggesting a set of possibilities and

3 In Campello et al. (2003) and Bornstein et al. (2004), the achievements of two other researchers who significantly contributed to the growth and consolidation of operational research in the country are described.

actions through the organisational process. Arenales et al. (2007) certify that operational research constitutes the development of scientific methodologies for complex systems, simulating strategies and decisions in the models. It aims to improve the way of operating, planning the different systems, supporting the definition of policies and taking actions based on science. This definition was proposed in 1967 on the front page of the English journal *Operational Research Quarterly*. In more recent concepts, operational research focuses on the decision-making process, using mathematical methods, software and hardware tools, and several interconnected scientific areas to articulate and model problems, identifying the objectives and constraints under which the system will operate to optimise results and increase corporate performance.

Sa, Arpini, and Santos (2019) define operational research as the science of knowledge that studies, develops, and uses mathematical methods to solve problems with the aim of optimising resources and also to assist in making more effective decisions and generating more profitable systems.

For Loesch and Hein (2009, p. 1), operational research is classified as a science of knowledge. They state that "as a science, [it] structures processes, proposing a set of alternatives and actions, forecasting and comparing values, efficiency and costs".

Currently, operational research is considered a quantitative tool companies use to solve problems in the most different segments. According to Moreira:

> Operational research deals with problems of conducting and coordinating certain operations in an organisation. It has been applied to many areas, such as industry, transport, telecommunications, finance, health, public services, military operations, etc. (Moreira, 2010, p. 3).

Corroborating the ideas of the authors mentioned above, operational research is a mathematical tool that contributes to the performance of decision-making in real-life circumstances. It can also be defined as an indispensable resource since it is presented as a strategy for making rational managerial decisions, replacing empirical decisions, generally used in the most diverse scenarios. Such actions demonstrate the flexibility of the technique, adaptable to any situation, as long as there are numerical data about the given process.

Hillier and Lieberman (2010, p. 4) cite examples of operational research applications to solve optimisation problems. Some examples cited are:

- Maximise production operations at chemical plants to achieve production objectives (increasing quantity and quality, for example) at minimum cost;
- Optimise the design of a road transport network and its routes, that is, deliver more in less time;
- Maximise profit in allocating aircraft types on domestic flights. In other words, deciding how many and what types and sizes of planes would make such flights, minimising the waste of resources (available seats, people, fuel, etc.);
- Schedule staff shifts to provide adequate customer service at a minimal cost.

Operational research has the fundamental objective of seeking the best use of resources, which may be, among others, the optimisation of the use of machines, raw materials, labour, etc.

One of the conditions for applying operational research is linear programming (LP).

> Linear programming is one of the most important instruments in operational research. It is the area of knowledge that provides a set of procedures aimed at dealing with problems involving the scarcity of resources. With linear programming, problems in which the best allocation of resources is sought, meeting the determined constraints and achieving optimisation, are subject to solution. These limitations may refer to the value or form of distribution of resources. (Corrar, Theóphilo, Bergamann, et al., 2007)

Operational research "[...] seeks to obtain the best solution –or optimal solution– to a problem" (Moreira, 2010, p. 3). Linear programming is one of the resources with the greatest potential in the search for this optimisation. This mathematical model is structured to solve "[...] problems that present variables that can be measured and whose relationships can be expressed through equations and/or linear inequalities" (Moreira, 2010, p. 10), also called a target function. According to the optimisation objective, the linear model, respecting the restrictions imposed by the situation, can minimise or maximise the result of this function (Moreira, 2010).

According to Caixeta-Filho (2014), linear programming is an improvement in solving a system of linear equations via successive inversions of matrices. It has the advantage of incorporating an additional representative linear equation related to the behaviour that must be optimised.

According to Loesch and Hein (2011), linear programming is shown as the resolution of problems of maximisation (profits) or minimisation (costs) of some objective, subject to a set of restrictions. The method used for this resolution is modelling, in which a mathematical model that summarises the essence of the problem is built. Also, according to these authors, in linear programming modelling, the following must be established: a) the variables of the problem, that is, what can be controlled and whose exact value one wants to know; b) the objective function, whenever one wants to maximise or minimise a certain objective, expressed as a function of the variables of the problem; c) the restrictions are also expressed as a function of the variables of the problem and limiting their combinations to certain limits.

Based on Santos et al. (2016), operational research, due to its multidisciplinary and scientific character, can produce significant contributions and be extended to practically all branches of knowledge, from engineering to medicine, especially business management.

In line with Almeida and Valente (2011), Costa (2013, p. 30) also points out that "[...] information technology applied to educational processes can offer a path of change for the old school. Of course, never as a panacea, but as one more tool at the service of teachers". According to Couto (2017, p. 175), the technological advancement of information technology and telecommunication, in addition to impacting the economy, also causes changes in cultural practices. In this way, it becomes essential that the school and its professionals use information and communication technologies (ICT), integrating them continuously into the teaching and learning processes to take advantage of the advantages they can provide at the pedagogical work and contribute to the construction of knowledge, as it is believed that these tools can be beneficial for meaningful learning of the content of the operational research discipline, specifically problem solving.

METHODOLOGICAL PATH

The research followed a qualitative approach. The group of research participants involved 24 students of the Business Administration course at Fisul College, located in Garibaldi, Serra Gaúcha. Two experiments were carried out with students/academics of this course attending the Operational Research subject.

We established steps to be developed during the mathematical modelling of problem situations, integrating meaningful learning and the development of conceptual maps. We followed the steps below:

1. **Diagnostic Probing** – It aims to identify students' prior or subsuming knowledge, allowing the planning of appropriate activities that favour individualised and meaningful learning through research instruments with questions involving problem situations encompassing the mathematical contents of proportionality, reading and interpretation problems, arithmetic operations, linear systems of 1st-degree equations/inequations and graphical representation of a 1st-degree equation/inequation.
2. **Advanced Organisers** – A process of solving situations related to operational research themes, which connects students' prior knowledge and what should be developed in solving and modelling real and contextualised situations presented by students in the experiment. This stage was planned as per Ausubel's theory of meaningful learning (2003), mathematical modelling, and operational research. At this stage, the resources used in learning and solving the planned problems involved the tool *Solver* to evaluate the advanced organisers, which served as a basis (anchor) for new learning involving a teacher/researcher mediation process.
3. **Evaluative Instrument** – To identify whether the students expanded their knowledge using the *Solver* tool differential, thus evaluating the advanced organisers' activity, which served as the focus for the new learning.
4. **Modelling of Operational Research Problems** – Solving problems investigated by students. This stage was subdivided into four phases: a. Construction of conceptual maps with the problems proposed by the students; b. Mathematical modelling with operational research problems proposed by students; c. Reconstruction of conceptual maps with the problems proposed by the students; d. Reconstruction of mathematical models and final resolution of problems.
5. **Closure Activities** – A survey of data from observations during the experiment, analysis of the problem-solving process and mathematical modelling, initial and final conceptual maps, and semi-structured interviews.

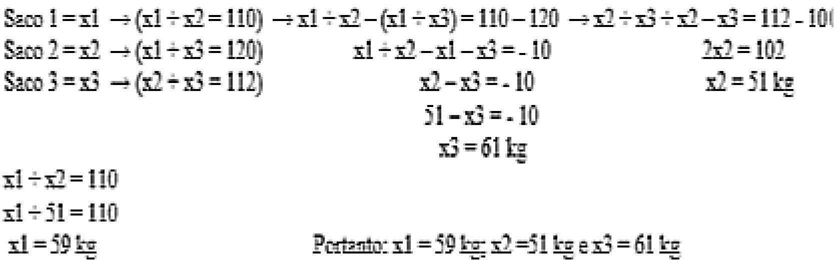
EXAMPLE DEVELOPED WITH RESEARCH PARTICIPANTS

One of the problems to be analysed in the Diagnostic Probing stage was: *A merchant had his employee weigh three sacks of corn. The employee returned exhausted and said: The first and second bags are 110 kilograms. The first and third together weigh 120 kilograms. And the second and third together are 112 kilograms. But the merchant wanted to know how many kilograms each bag had. So, please find this out to help the employee not get too tired. Describe the process for solving the issue.*

We noticed that Student 2, as shown in Figure 4, obtained the answer using a system of equations with three equations and three unknowns, with a predominance of algebraic procedures.

Figure 4

Student 2's production.


Saco 1 = x1 → (x1 + x2 = 110) → x1 + x2 – (x1 + x3) = 110 – 120 → x2 + x3 + x2 – x3 = 112 - 10(
Saco 2 = x2 → (x1 + x3 = 120) x1 + x2 – x1 – x3 = - 10 2x2 = 102
Saco 3 = x3 → (x2 + x3 = 112) x2 – x3 = - 10 x2 = 51 kg
51 – x3 = - 10
x3 = 61 kg
x1 + x2 = 110
x1 + 51 = 110
x1 = 59 kg
Portanto: x1 = 59 kg; x2 = 51 kg e x3 = 61 kg

In the first experiment, 13 students could solve the problem by applying algebraic knowledge, such as solving a system of equations using the substitution method. In comparison, three students completely missed the issue. In the second experiment, seven out of eight students answered the question completely right. Student 4 used system representativeness and resolution. However, we observed that the students seemed to present the subsumers related to the capacity of representation and resolution through a problem situation.

In the second stage, of the Advanced Organisers, the problem was: *There are 45 vehicles in a supermarket parking lot, including cars and* *motorcycles. After a count, 162 wheels were counted. How many vehicles are there of each type?*

We realised that around 96% of the participating academics knew how to represent and solve the system of 1st-degree equations using the substitution method. The others used the addition or proportionality method. We also noticed that students 3, 8, and 14 solved it using the trial method, thus obtaining successful answers. Thus, using their mathematical knowledge, students recognised and defined problems, equated solutions, thought strategically, introduced changes in the production process, acted preventively, transferred and generalised knowledge and exercised decision-making in different degrees of complexity.

Given the results, we understood that the students attending the Operational Research subject presented the subsumers necessary to start modelling linear programming problem situations.

Regarding the stage of the Evaluative Instrument, we had: *A clothing company is considering how much to produce of its two suit models, namely the* Executivo Master [Master Executive] *and the* Caibem [Fits Well], *to maximise profit. It is impossible to produce as much as you want of each one, as there are limitations on the hours available for machine sewing and manual finishing. For sewing, there is a maximum of 180 machine hours available; for finishing, there is a maximum of 240 worker hours. In terms of unit profit and production, the two suit models have the following characteristics:*

a) Executive Master	*b) Caibem*
- Unit profit: BRL 120.00	*- Unit profit: BRL 70.00*
- Sewing machine hours per unit: 2	*- Sewing machine hours per unit: 1*
- Finishing worker hours per unit: 2	*- Finishing worker hours per unit: 4*

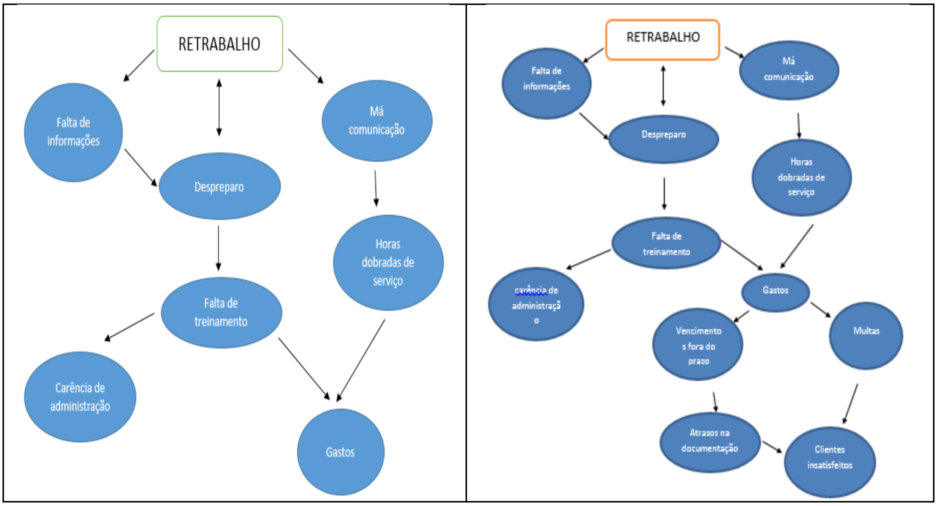
Formulate the problem as a linear programming model. Find the optimal solution.

As for the result, students hit 100%; that is, all the students could find the correct answer through a system of equations/inequations aided by the tool, which leads us to infer that the students presented the subsumers related to the ability to solve a possible and determined system of equations through the support process for new learning.

The next stage of the experiment the professor/researcher requested was for the students to investigate and propose professional-life problems involving the topics of interest. For the analysis, the stages were grouped with the construction of conceptual maps and their reconstruction. Figure 5 shows Student 18's completion of the construction and reconstruction of the initial and final conceptual maps, interconnecting concepts applied to management.

Figure 5

Student 18's initial and final conceptual map.



Through the analysis of Student 18's map in Figure 5, we see that he listed aspects aimed at learning concepts and enabling the association between them, thus favouring the progressive differentiation of general concepts, going on to intermediaries and, finally, reaching specific ones, constituting a strategic element with potential effectiveness (Moreira, 2003).

The maps represent the knowledge established by concepts, and their construction begins from the domain of knowledge of each subject, i.e., this construction "[...] is not carried out artificially, but rather takes account the knowledge of the world to which one belongs and how one responds to it"

(Cervantes, 2006, p. 30). Also, according to the author, "for the organisation of a domain, from its representation to its recovery, first, the concepts that make up this field of knowledge and the relationships that are established between them are studied" (Cervantes, 2006, p. 26).

Per Student 18's maps, the theoretical concepts were expanded when associated with knowledge related to his experiences, thus aiming at a space concerned with learning and the meanings for life/company, which forms active, critical, and conscious subjects. According to Rodrigues (2011, p. 60), "the conceptual maps can be used in the organisation and the analysis of the content, [...] as a differentiated didactic resource to represent the information of the textual form".

The construction of knowledge is verified with the observation of events and objects that exist around us. These, in turn, are not discovered, but constructed by nature or by human beings, such as knowledge. Therefore, Novak (1984) defines the concept as regularity in events or objects, designated by specific terms used as keywords in the conceptual map. Thus, there is conceptual learning, which allows the representation of particular symbols, which Ausubel called concepts, being defined as objects, events, situations or properties that have attributes of standard criteria and are designated by the same sign or symbol (Ausubel, 2003, p. 94).

The construction of conceptual maps by the student or the teacher establishes a skilful point with potential efficiency when the teacher exposes the content present in their cognitive structure through their presentation and, when built by the student, falls into a perspective of meaningful learning.

Given the results observed concerning the initial and final maps, we can infer that the students represented them in different ways, with different subsumers, thus having changes that were perceived differently and, consequently, evolved, mainly by inserting concepts related to management, where it is related to the Administration course linked to the Operational Research subject.

Therefore, we resume the mathematical modelling with operational research problems proposed by students and the reconstruction of mathematical models. To illustrate the changes in the conception of the initial problem situation concerning the final mathematical model, as shown in Table 1, we give Student 2 as an example.

Table 1

Comparison between Student 2's initial and final problem situation

Initial problem situation	Final problem situation
The large injection moulding machine injects various types and models of plastic parts that are components of products produced in the company. Initially, we will only work on some parts of the lawnmower and wheelbarrow product. The company takes three hours to produce a lawnmower unit (P1). Manufacturing a complete wheelbarrow unit (P2) takes two hours. The time studied is quarterly, considering 2,100 hours, as the machine works 24 hours/7. X_1 *= housing* X_2 *= bucket* $3 X_1 + 2 X_2 <= 2100$	*The Romi 800-ton injection machine mainly injects two models of plastic parts that are components of products produced by the company. Housing P1 is part of the lawnmower, and bucket P2 is part of the wheelbarrow. The profit obtained by the company from the sale of the products is BRL 650.00 for product P1, the lawnmower, and BRL 120.00 for product P2, the wheelbarrow. The company takes three hours to produce a lawnmower unit (P1). Manufacturing a complete wheelbarrow unit (P2) takes two hours. The time studied is quarterly, considering 2,100 hours, as the machine works 24 hours/7. The expected demand for lawnmowers (P1) is 620 units quarterly, and wheelbarrows (P2) is 1,050. The challenge was developing a production plan for the company to maximise profits, specifically considering these two items.*

Table 1 shows Student 2's very simplified view of the whole in the initial problem situation, i.e., it is not correctly translated from natural language to mathematical language, as in the example, it was unclear whether the problem was about minimising or maximising. The inclusion of new restrictions and non-negativity variables, faced with the initial problem situation, becomes more evident in the final problem situation, thus defining the objective function of the problem itself.

The description of the final mathematical model is presented below:

P_1 = product 01 = housing (lawnmower)

P_2 = product 02 = bucket (wheelbarrow)

Therefore:

*P_1 profit: 650.00 * X_1 (P_1 profit x amount of P_1 production)*

*P_2 profit: 120.00 * X_2 (P_2 profit x amount of P_2 production)*

Where the Total Profit: $L = 650 X_1 + 120 X_2$

So, the goal is to maximise

$L = 650 X_1 + 120 X_2$

Restrictions existing in the mathematical model system:

The availability of 2,100 production hours for a quarter.

Hours occupied with P_1: 3 X_1 (use per unit x quantity produced).*

Hours occupied with P_2: 2 X_2 (use per unit x quantity produced).*

Total hours occupied in production: $3 X_1 + 2 X_2$

Total availability of 2,100 hours.

Descriptive restriction of the situation: $3 X_1 + 2 X_2 <= 2100$

Market availability for the products:

For P_1: 620 units

Quantity to be produced of P_1: X_1

Descriptive restriction:$X_1 <= 620$

For P_2: 1050 units

Quantity to be produced of P_2: X_2

Descriptive restriction: $X_2 <= 1050$

Therefore, the construction of the mathematical model:

Max $L = 650 X_1 + 120 X_2$

Restrictions:

$3 X_1 + 2 X_2 <= 2100$

$X_1 <= 620$

$X_2 <= 1050$

$X_1 >= 0; X_2 >= 0$

Table 2 presents the results obtained in the Solver software:

Table 2

Student 2's Solver *calculation.*

X_1	*620*		
X_2	*120*		
Target function	*417400*		
Restriction Function	*2100*	<=	*2100*
	620	<=	*620*
	120	<=	*1050*
	620	>=	*0*
	120	>=	*0*

With the answers from the initial mathematical model, there was a comparison of the reality of the experiment, with two hypotheses occurring, where the results obtained according to the student's conception were accepted in relation to the problem situation, being adequate to the process in question. Others envision new data to be observed, corroborating the dynamics of the modelling process and changing its mathematical model, since Warwick (2007) suggests that modelling occurs in stages, in particular, compared with reality.

Finally, the last step was the Closure Activity, which asks the following: *How will the results obtained by the* Solver *software be used in the problem situations (organisation/company) to which they apply?*

As Rodrigues and Santos (2013) and Ragsdale (2009) point out, Student 15's speech is noteworthy:

> *The company already has a range of fixed customers. To serve this public, the hair salon was working only by appointment.*

Because they did not know the tool, they worked with service fittings between one procedure and another. The problem is that there was either idle time or insufficient time to finish carrying out the procedures. With the results obtained with the tool, time became better managed, and Solver proved that this is how you will have the greatest profit. (Student 15)

Regarding Student 15's speech, when dealing with the problem analysed in a small family business, the conditions for interpreting mathematical problems and for all areas of knowledge, in particular, the "hair salon", brought significant experiences, favouring the development of skills in solving everyday problem situations and contributing to the understanding of the contents of the Operational Research subject in activities focused on reality. When analysing his work, Student 15 envisioned the ability to think strategically and introduce changes in the productive process of the work developed.

Therefore, it is clear that there are indications of the establishment of some strategic actions taken by the responsible sector of the institution, such as: "increase in manpower", "evaluation of leftovers", "reduction of purchases", and hiring of a person to "think and act strategically", as well as the proposition of changes in the productive systems. However, there is insufficient evidence to affirm that such goals and actions have been implemented in the respective organisations at stake.

FINAL CONSIDERATIONS

We could identify the elaboration of teaching activities aimed at studying operational research, associating technological resources and proposing mathematical modelling activities, seeking to offer teaching environments that allow meaningful learning.

A diagnostic probing exercise was applied to check the students' prior knowledge. The results presented, analysed based on Ausubel's theory of meaningful learning (2003), evidenced the presence of subsumers, which showed a relationship with the resolution capacity and recognition of the proportionality relationship, directly or inversely. Some of the results presented by the students were not satisfactory, requiring the advanced organisers, a pedagogical planning tool that aimed to help students with difficulties in acquiring knowledge. After applying the instrument, we verified that the difficulties were reduced.

One of the ways that evidence the perception of meaningful learning happens when the students formulate and solve their research problems based on real situations, applying this in the final activity of mathematical modelling. This can be seen, for example, in relation to Student 4, when he seeks to establish cost control for making bread, or Student 9, who seeks a way to maximise profit in cheese production. In these cases, the degree of independence acquired by the students in the final mathematical modelling activity was in evidence.

Evidence of meaningful learning was also perceived throughout the student's career when he related to the worked concepts. Meaningful learning happens all the time, continuously and progressively, with a main focus on understanding the facts, transferring knowledge, and capturing meanings of situations not experienced in everyday life.

In general, concerning the identification of final, constructed, or expanded knowledge, we observed that the Operational Research subject enabled students to understand the concepts in the two experiments developed since the research participants could make adequate use of the concepts in solving the proposed problems and express them appropriately in natural language, presenting creative solutions and, through discussion, reflection, and organisation of the necessary knowledge, present the resolution in group work, mediated by the professor/researcher.

AUTHORSHIP CONTRIBUTION STATEMENT

AF and CLOG conceived the presented idea. AF developed the theoretical framework, carried out the activities, and collected data under CLOG's supervision. AF and CLOG verified the data. All authors actively participated in the discussion of the results. CLOG revised and approved the final version of the work.

DATA AVAILABILITY STATEMENT

The data that support the results of this research will be made available by the corresponding author, AF, upon request.

REFERENCES

Almeida, M. E. B. & Valente, J. A. (2011). *Tecnologias e currículo: Trajetórias convergentes ou divergentes?* Paulus.

Alro, H., Skovismose. (2010). O. *Diálogo e Aprendizagem em Educação Matemática*. Tradução de Orlando Figueira. 2. ed. Autêntica.

Anastasiou, L. das G. C.; Alves, L. P. (orgs.). (2006). *Processos de ensinagem na universidade: pressupostos para as estratégias de trabalho em sala de aula.* 6. ed. Univille.

Arenales, Marcos, Armentano, Vinícius, Morabito, Reinaldo, & Yanasse, Horacio. (2007). *Pesquisa Operacional: para cursos de engenharia.* 6. ed. Elsevier. 524 p.

Ausubel, David Paul. (1963). *The psychology of meaningful verbal learning.* Grune and Stratton.

Ausubel, David Paul, Novak, Joseph D. & Hanesian, Helen. (1980). *Psicologia Educacional.* Trad. De Eva Nick e outros. Interamericana.

Ausubel, David Paul. (2003). *Aquisição e retenção de conhecimentos: uma perspectiva cognitiva.* Plátano.

Ausubel, David Paul. (1973). *Algunos aspectos psicológicos de la estrutuctura del conocimiento.* El Ateneo.

Ausubel, David Paul. (1976). *Psicología educativa. Un punto de vista cognoscitivo.* Trillas.

Barbosa, Jonei Cerqueira. (2001). *Modelagem Matemática: Concepções e Experiências de Futuros Professores*. 253f. Tese (Doutorado em Educação Matemática) -Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista, Rio Claro.

Bassanezi, Rodney Carlos. (2002). *Ensino-aprendizagem com Modelagem Matemática: uma nova estratégia.* Contexto.

Bilinski, P. A. & Fernandes C. W. N. (2016). *Aplicação da Pesquisa Operacional na otimização da lucratividade de uma empresa do segmento de marcenaria*.

Borba, M. & Villareal, M. E. (2005). *Humans-with-Media and the Reorganization of Mathematical Thinking.* Springer.

Bornstein, C. T., Yanasse, H. H. & Abreu, N. M. M. Roberto Galvão. (2004). 60 anos – reflexões, retrospectiva e reconhecimento. *Pesquisa Operacional*, *24*, 3-6.

Borssoi, A. H. (2017). Tecnologias Digitais como componentes de Ambientes Educacionais voltados à Aprendizagem do Aluno. In: Silva, A. P; Dalto, J. O, Org(s). *Educação Matemática e Pesquisa: algumas perspectivas*. (p. 143-164). Livraria da Física.

Burak, Dionisio & Aragão, Rosália M. R de. (2012). *A Modelagem Matemática e relações com a Aprendizagem Significativa.* CRV.

Caixeta-Filho, Vicente José. (2014). *Pesquisa Operacional: técnicas de otimização aplicadas a sistemas agroindustriais.* 2. ed. Atlas.

Campello, R. E., Ribeiro, C. C., Pereira, M. V. F. & Abreu, N. M. M. (2003). Nelson Maculan Filho: cientista e educador. *Pesquisa Operacional*, *23*, 5-28.

Cervantes, B. M. N. (2006). *Terminologia do processo de inteligência competitiva: estudo teórico e metodológico.* Eduel.

Corrar, L. J.; Theóphilo, C. R. (coordenadores). (2007). *Pesquisa Operacional para decisão em contabilidade e administração: contabilometria*. Atlas.

Costa, F. A. (2013). O potencial transformador das TIC e a formação de professores e educadores. In: Almeida, M. E. B., Dias, P., & Silva, B. D. (orgs.). *O cenário de inovação para a educação na sociedade digital*. Loyola.

Couto, Edvaldo; Ferraz, M. do C. Gomes; Pinto, J. de C. Almeida. (2017). Tecnologias digitais e a promoção da eficácia e da equidade no contexto escolar. *Textura*, Canoas, *19*(40), 173-188.

Diniz, L. N.& Borba, M. C. (2012). Leitura e Interpretação de Dados Prontos em um Ambiente de Modelagem e Tecnologias Digitais: o mosaico em movimento. *Bolema*, *26*(43), 935-962.

Gowin, D.B. (1981). *Educating*. Cornell University Press.

Hillier, Frederick S. & Lieberman, Gerald Jerry. (2010). *Introdução à Pesquisa Operacional.* McGraw-Hill.

Lévy, P. (2000). *Cibercultura.* 2. ed. 34.

Loesch, Cláudio; Hein, Nelson. (2009). *Pesquisa Operacional: fundamentos e modelos.* Saraiva.

Moreira, Marco Antônio. (1999). *Teorias de aprendizagem.* EPU.

Moreira, Marco Antônio & Masini, Elcie Aparecida Fortes Salzano (2006). *Aprendizagem Significativa: a teoria de David Ausubel.* 2ª ed. Centauro.

Moreira, Marco Antônio. (2011). *Aprendizagem Significativa: a teoria e textos complementares.* Livraria da Física.

Moreira, Marco Antônio. (2011a). A Teoria da Aprendizagem Significativa como Teoria Construtivista. *Aprendizagem Significativa em Revista*, *1*(1), 36-57.

Moreira, Marco Antônio. (2011b). *Aprendizagem Significativa: a teoria e textos complementares.* Livraria da Física.

Moreira, Marco Antônio. (2010). *Aprendizagem Significativa Crítica.* Instituto de Física da UFRGS. 2ª edição.

Moreira, Marco Antônio & Masini, E. A. F. S. (1982). *Aprendizagem Significativa: a teoria de aprendizagem de Davi Ausubel.* Moraes.

Moreira, Marco Antônio & Greca, Ileana M. (2003). Cambio Conceptual: análisis crítico y propuestas a la luz de la teoría del aprendizaje significativo. *Ciência & Educação*, *9*(2), 301-315.

Novak, J. D. & Gowin, D. B. (1984). *Learning How to Learn.* Cambridge University Press.

Novak Joseph D & Cañas, Alberto J. (2006). The origins of the concept mapping tool and the continuing evolution of the tool. *Information Visualization*, *5*, 175–184.

Penteado, M. G. (2004). *Redes de trabalho: expansão das possibilidades da informática na educação matemática da escola básica.* In: Bicudo, M.A.V; Borba, M.C. (Orgs.). *Educação Matemática em movimento* (p. 283-295). Cortez.

Ragsdale, C. T. (2009). *Modelagem e Análise de Decisão*. 6. ed., Cengage.

Ribeiro, R. João. (2011). *Curta de animação como organizador prévio no ensino de Física*. Dissertação (Mestrado) - Programa de Pós-

Graduação em Ensino de Ciência e Tecnologia, Universidade Tecnológica Federal do Paraná. Ponta Grossa. 143 f.

Rihs, A. A. & Almeida, C. F. (2017). A teoria da Aprendizagem Significativa: o enfoque de David Ausubel. *Revista Multidisciplinar do Nordeste Mineiro – Unipac*.

Rios, Terezinha Azerêdo. (2010). *Compreender e ensinar: por uma docência da melhor qualidade.* 8. ed. Cortez.

Rodrigues, M. R. (2011). *Os mapas conceituais para a visualização de conceitos de áreas do conhecimento em unidades de informação*. Trabalho de Conclusão de Curso (Graduação em Biblioteconomia) – Universidade Estadual de Londrina, Londrina. 112f.

Rodrigues, E. C. N. & Santos, Y.B.I. (2013) Aplicação da Programação Linear na Minimização dos Custos de Produção em uma Indústria de Processamento de Açaí de Pequeno Porte no Município de Belém. In: *Anais do XX SIMPEP*.

Sá, L. C.; Arpini, B. P. e Santos, P. H. (2019). *Pesquisa operacional no campo da logística: explorando interfaces.* Edifes.

Santos, M., Lima I. C., Paixão A. C., Dias F. C. & Reis, M. F. (2016). *Proposta de otimização do mix de produção utilizando o método simplex: um estudo de caso de uma confecção de moda íntima do município de Cordeiro* – RJ.

Santos, J. Almeida, França, K. Vieira & Santos, L. S. Brun. (2013). *Dificuldades na aprendizagem da Matemática*.

Skovsmose, Ole. (2008). *Desafios da reflexão em educação Matemática.* Papirus.

Warwick, J. (2007). Some reflections on the Teaching of Mathematical Modeling. *The Mathematical Educator*, *17*(1), 32-41.

Zanato, A. R.; Strieder, D. M. e Campos, T. A. (2020). O uso das TICS nas escolas brasileiras: percepção dos professores de ciências. *Revista Atlante Cuadernos de Educación y Desarrollo*.