

Articulated Video Production Between Teachers and Training Teachers as a Proposal for the Teaching of Modern and Contemporary Physics

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ABSTRACT

Background: The Teaching of Modern and Contemporary Physics (MCP) appears in the PCN + and in the National Common Curricular Base (BNCC) for High School. Its application encounters cognitive obstacles by students, added to the little didactic literature or research in teaching, as well as didactic experiments. **Objectives:** This work presents a project to develop didactic videos for teaching MCP. It is an articulation between undergraduate and graduate courses, in the conception and use of Information and Communication Technologies (ICT) in MCP by teachers. **Design:** Conception is based on Gowin's Triad, where teaching materials are one of the vertices of the sharing of meanings involving teachers and students, as well as they are designed with an emphasis on scientific rigor and, at the same time, seek to arouse the interest of the target audience. The materials are licensed as Open Educational Resources and can be used individually, but together they constitute an organic whole in several MCP themes. **Setting and Participants:** Master's students in Science Teaching and initial and continuing training Physics teachers, from a Public University. **Data collection and analysis:** To assess the impact, an analysis was made of the number of accesses and placements (ranking), using Internet search tools as well as application in the classroom. **Results:** the number of accesses on the web and perceptions in the classroom point to the sharing of meanings predicted by Gowin. **Conclusions:** Results place this research as a concrete possibility to combine scientific training, research in teaching and commitment to the school.

Keywords: modern and contemporary physics teaching; Gowin's Triad; information and communication technologies; open educational resources.

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A Produção de Vídeos Articulada entre Professores e Licenciandos como Proposta para o Ensino de Física Moderna e Contemporânea

RESUMO

Contexto: O Ensino de Física Moderna e Contemporânea (FMC) figura nos PCN+ e na Base Nacional Comum Curricular (BNCC) do Ensino Médio. Sua aplicação encontra obstáculos cognitivos pelos estudantes, somada à pouca literatura didática ou em pesquisa em Ensino, bem como experimentos didáticos. **Objetivos:** O presente trabalho apresenta um projeto de desenvolvimento de vídeos didáticos para o ensino de FMC. Trata-se de uma articulação entre graduação e pós-graduação, na concepção e uso de Tecnologias de Informação e Comunicação (TIC) em FMC por professores. **Design:** Concepção tem como base a Triade de Gowin, onde materiais didáticos são um dos vértices do compartilhamento de significados envolvendo professores e estudantes e são concebidos com ênfase no rigor científico e buscam despertar interesse no público alvo. Os materiais são licenciados enquanto Recursos Educacionais Abertos e podem ser utilizados individualmente, mas, em conjunto, constituem um todo orgânico em diversos temas da FMC. **Ambiente e participantes:** Mestrandos de um mestrado profissional em Ensino e os Licenciandos em Física, professores em formação inicial e continuada, de uma Universidade Pública. **Coleta e análise de dados:** Para avaliar o impacto foi realizada uma análise do número de acessos e às colocações (*ranking*), com ferramentas de busca na internet bem como aplicação em sala de aula. **Resultados:** o número de acessos na *web* e as percepções em sala de aula apontam para o compartilhamento de significados previstos por Gowin. **Conclusões:** Resultados colocam essa pesquisa como uma possibilidade concreta em conjugar formação científica, pesquisa em ensino e compromisso com a escola.

Palavras-chave: ensino de física moderna e contemporânea, Triade de Gowin, recursos educacionais abertos, tecnologias de informação e comunicação.

INTRODUCTION

The first quarter of the 21st century will be remembered in the future for having been a period in which the status of postmodernity, which emerged in the post-war period by proposing the vision of nature structured by language to the detriment of rational thinking in science and philosophy as a means of describing reality, as well as Enlightenment (Dusek, 2009), serves as a subsidy for the establishment of a series of post-truths (Lima *et al.*, 2019), such as scientific negationism, flat-earth believers, aversion to vaccination campaigns and, with regard to modern and contemporary physics (MCP), a series of charlatanisms, such as “quantum coaching,” “quantum consciousness”, among others. As proposed by Lima *et al.* (2009), it is necessary to rethink various aspects of “teaching science” in the face of the proliferation of post-truths, which involves reviewing curricula, teacher education, and also the means of technological mediation, so that it is possible to establish a dialogic relationship with students so that the knowledge to be mediated makes sense to them (Moreira, 2011).

This panorama places the need to teach modern and contemporary physics (MCP) in high school, or early higher education as challenging, constituting a central theme in research in physics education today (Valadares & Moreira, 1998; Pinto & Zanetic, 1999; Cavalcante, Jardim & Barros, 1999; Osterman & Moreira, 2000; Ostermann &

Cavalcanti, 2001; Machado & Nardi, 2003; Rezende Jr & Souza Crus, 2003; Machado & Nardi, 2006; Singh, 2008; Pereira & Ostermann, 2009; Ayene, Kriek & Dامتie, 2011; Domingui, 2012; Morais & Guerra, 2013; Dangur *et al.*, 2014; Bezerra-Jr *et al.*, 2015; Silveira & Girardi, 2017; Hansson, Leden & Pendrill, 2019). At the same time that this curricular component implies the understanding of phenomena and effects that escape the perceptions and interpretations elaborated by classical physics - which is more sensorial and close to macroscopic representations -, there is also the need for more advanced mathematical constructions, especially when considering the high-school students' education. In this context, there are specific and subtle difficulties, beyond those already traditional to classical physics, regarding its didactic transposition (Brockington & Pietrocola, 2005; Coimbra, 2016).

Quantum physics is fundamentally a representation of the microscopic world, and its development is often counterintuitive. Its transposition into the perceptions of the subjects, who, as a whole, make up the students' realities, is based on elaborate experiments that, from the didactic point of view, present difficulties related to the cost of equipment and the dynamics necessary for laboratory classes, in general different from that traditional in vogue in classical physics teaching. For example, some significant experiments associated with quantum physics require the use of high voltage sources, discharge tubes with vacuum control, measuring devices with more sophisticated electronics, lasers, and radioactive sources that present risks to the safety and health of those involved; besides, the complexity of the experiments also translates into a longer teaching time for classes.

At the same time, students are immersed in a reality in which everyday artefacts are entirely influenced by quantum physics (lasers, computers, *smartphones*, *tablets*, and video and music playback devices, among others). This aspect can be considered from the perspective of the formation of critical citizens and aware of the technological options produced and present in society, constituting another challenge for the preparation of classes by teachers, which refers to the theme teacher education (Auler & Delizoicov, 2006). Besides, we understand that the teaching of MCP, as it is close to current themes, assumes contours in the also relevant task of awakening vocations to science (Vilches and Gil-Pérez, 2012).

Recent research in physics teaching indicates that there is little production on cognitive processes in MCP (Pereira & Ostermann, 2009), but highlights the existence of alternatives with innovative character (Araújo & Housume, 2013). Among these, we highlight instrumentation as a way of inserting modern physics (Vicentini *et al* 2011), the use of information and communication technologies (Pereira *et al.*, 2008), the analysis of the inclusion of the theme in school curricula in Brazil and abroad (Lobato & Greca, 2005), the production of books with didactic transposition proposals by experiments (Chesman *et al*, 2004) or via historical and philosophical reflections (Freire Jr *et al.*, 2010), as well as the various educational objects available in public repositories such as the International Bank of Educational Objects - BIOE (Brasil, 2008a), the Portal do Professor (Brasil, 2008b) and the EduCapes (Brasil, 2020), where educational products produced within the scope of professional masters' degrees in the area of education are deposited.

In this context, we highlight the work of Macêdo and collaborators (2014) indicating the need for further studies on the use of information and communication technologies (ICT) with MCP, given that, despite the opening of perspectives in its use, this area has been a little explored in Brazil. Therefore, we will discuss a proposal to produce didactic videos on MCP to be used in high school. Its elaboration takes place at the interface between teacher education – in a physics teaching degree course – and continuing education – in a professional master’s degree in the teaching area.

THE MCP AND THE HIGH SCHOOL CURRICULUM

By proposing to articulate teachers in their initial stage of training (undergraduates) with teachers in continuing education (professional master’s students in teaching), by the nature of these courses and the space of action, the school has a preponderant position. That said, it is important to place the MCP teaching within the curricular guidelines for high school education, in view of the recent changes inserted in the Base Nacional Comum Curricular para o Ensino Médio (National Common Curricular Base for High School) – BNCC (Brasil, 2017).

The first explicit insertion of the MCP in guiding documents for high school (the former Segundo Grau, according to the Brazilian Education Guidelines and Bases Act of 1996) dates back to the beginning of this century, in the National Curriculum Parameters, the PCN+ (Brasil, 2002), which situate the MCP as a structuring theme:

Some aspects of so-called modern physics will be indispensable to enable young people to acquire a more comprehensive understanding of how matter is constituted so that they have contact with different and new materials, liquid crystals, and *lasers* present in technological utensils, or with the development of electronics, integrated circuits, and microprocessors. [...] indicates a theme capable of organising competencies related to the understanding of the microscopic material world. (PCN+, p. 67)

This structuring character of the MCP remains in the current BNCC, which, among its basic principles, provides for the need to articulate contemporary scientific knowledge with the students’ realities, making them able to model, interact, apply, and transcend those knowledges in their aspirations and needs, whether professional or social. The MCP stands out most prominently in the formative itinerary “Natural Sciences and their Technologies,” according to:

III – natural sciences and their technologies: deepening the structuring knowledge for the application of different concepts in social and work contexts, organising curricular arrangements that allow studies in astronomy, metrology, **general, classical, molecular, quantum, and mechanical physics**, instrumentation,

optics, acoustics, the chemistry of natural products, analysis of physical, and chemical phenomena, meteorology and climatology, microbiology, immunology and parasitology, ecology, nutrition, zoology, among others, considering the local context and the possibilities of supply by education systems. (Brasil, 2017. Author's emphasis)

In Table 1, we list some skills and competencies of this formative itinerary in which there is dialogic space for insertions of the MCP in school.

Table 1
BNCC's relations with the MCP (Brasil, 2017, p. 563).

Specific Competence	Associated Skills
<p>1. Analyse natural phenomena and technological processes, based on interactions and relationships between matter and energy, to propose individual and collective actions that improve production processes, minimise socio-environmental impacts and improve living conditions at the local, regional, and global levels.</p>	<p>(EM13CNT101) Analyse and represent - with or without the use of specific digital devices and applications - the transformations and conservations in systems involving the amount of matter, energy, and movement to predict their behaviours in everyday situations and in productive processes that prioritise sustainable development, the conscious use of natural resources and the preservation of life in all its forms.</p> <p>(EM13CNT103) Use knowledge about radiation and its origins to assess the potential and risks of its application in standard equipment, health, environment, industry, agriculture, and electricity generation.</p>
<p>2. Analyse and use interpretations of the dynamics of Life, Earth, and the Cosmos to elaborate arguments, make predictions about the functioning and evolution of living beings and the Universe, and support and defend ethical and responsible decisions.</p>	<p>(EM13CNT201) Analyse and discuss proposed models, theories, and laws at different times and cultures to compare distinct explanations about the emergence and evolution of Life, Earth, and the Universe with currently accepted scientific theories.</p> <p>(EM13CNT205) Interpret results and make predictions about experimental activities, natural phenomena, and technological processes, based on the notions of probability and uncertainty, recognising the explanatory limits of the sciences.</p>
<p>3. Investigate problem situations and evaluate applications of scientific and technological knowledge and its implications in the world, using procedures and languages specific to the Natural Sciences, to propose solutions that consider local, regional and/or global demands, and communicate their findings and conclusions to various audiences, in different contexts and through different media and digital information and communication technologies (DICT).</p>	<p>(EM13CNT302) Communicate to varied audiences, in various contexts, the results of analyses, research and/or experiments, elaborating and/or interpreting texts, graphs, tables, symbols, codes, classification systems and equations, through different languages, media, digital information and communication technologies (DICT), in order to participate and/or promote debates on scientific and/or technological topics of sociocultural and environmental relevance.</p> <p>(EM13CNT308) Investigate and analyse the operation of electrical and/or electronic equipment and automation systems to understand contemporary technologies and evaluate their social, cultural, and environmental impacts.</p>

Regarding the PCN+, the BNCC advances in the sense of not explicitly proposing the teaching of the MCP *per se*, but in view of the relationships and applications mentioned above. This flexible curricular organisation, as proposed by this common national base, by problematising the students' reality, opens the perspective of discussing, exposing and building with them the physical knowledge to be transposed necessary for the interpretation and broadening horizons of their respective realities, without falling into the dichotomy "classic versus modern," so present in teaching materials and methodologies on the subject. Explicit mention is also made of the DICT, incipient at the time of the PCN+ (2002), but somewhat pervasive in the current period.

To complete the framework of challenges related to the teaching of modern and contemporary physics at the high school level, besides preparing the students, it is essential to think about the training of the preservice and active physics teachers who need to (re)visit the theme. These issues have been intensively addressed in the documents of scientific societies, such as the Brazilian Society of Physics (SBF, 2005) and the American Association of Physics Teachers (Galvez & Singh, 2010).

THE CHOICE OF ICTS: EDUCATIONAL OBJECTS AND DIDACTIC VIDEOS

The purpose of this work is to approach the MCP in the production of videos, involving teachers in initial or continuing education. The need for the approach from the MCP and mediation by the ICTs for both audiences aims to internalise a culture of making the MCP teaching dialogic with the school culture (teachers and students) and making ICTs not the panacea for the school, but be the object of teacher training so that teachers assume them in their planning and pedagogical practices. Angotti (2015) places the insertion of ICTs and contemporary science in the current context of Brazilian education:

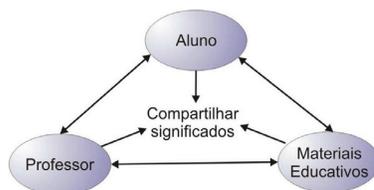
Among the resistances of the school tradition, it is worth highlighting the crystallisation of long singular sequences of teaching, guided much more by systematic repetition poorly reflected (for example, kinematics and geometric optics) than by contemporary demands, which are more committed to contextualisation, interdisciplinarity, and transversality, without suppressing the disciplines and the fluent and critical use of the DICTs. The presence of science and technology in the contemporary world seems to justify by itself the need for its teaching, even if the school contents do not treat current knowledge as they should, with the use and fluency of the DICTs as a not only fundamental, but imperative requirement. (Angotti, 2015)

Their production - also in the form of teaching materials with the participation of teachers to break the paradigm of the "client teacher" (Saavedra Filho, 2016)-, ends up being a possibility where, in the elaboration of their materials to be used as mediation instruments, teachers and students share meanings, basic negotiation of the teaching, and

learning process. This perspective forms the basis of Gowin's teaching model (Moreira, 2011), where a teaching-learning process is composed of a teacher-students-teaching materials triad, sharing meanings (Figure 1).

Figure 1

The triad in Gowin's teaching model (Moreira, 2011, p. 185)



For Gowin (1981, *apud* Moreira, 2011), “Teaching is consumed when the meaning of the material that the student captures is the meaning that the teacher intends this material to have for the student.” In the proposal of the work in question, the learning for teachers who intend to share meanings of the MCP with their students also encompasses the elaboration of didactic materials in the form of educational objects, which, in turn, also embody the notes proposed by Angotti (2015), so that Gowin's triad is included in their elaboration.

Educational objects (EO) are defined as any entities, digital or otherwise, that can be used, reused and referenced in technological support to learning. Among the EOs are hypermedia content, instructional content, learning objectives, instructional *software*, and *software tools*, as well as events referenced during technological support to learning (LTSC & IEEE, 2007). Broadly speaking, any set of graphs and images combined with text or any other element (hypertext/hypermedia) can be considered educational objects (Gama, 2007; Tarouco *et al.*, 2003). Also according to Pessoa and Benitti (2008), the educational objects are responsible for replacing old methods, such as teleclasses, and carry a range of advantages such as faster distribution, access by a bigger audience, and the possibility of reuse. Actually, information technologies have accelerated the development of EOs, enabling the use and dissemination of didactic content available on the Internet in different formats (Gama, 2007). In the world of media convergence, all users are affected by communications on multiple platforms (Schmidt, 2011), something especially interesting for teaching materials.

The elaboration of these didactic materials in the format of educational objects cannot be done voluntarily or randomly, since the sharing of meanings provided by Gowin would be frankly jeopardised. It is also necessary to take into account applications in different contexts, so that the same EO can take part in different teaching-learning processes in different schools and realities. For the teacher not to be necessarily an intrinsic author (a somewhat unreal perspective in Brazilian basic education, especially in the public network), the EOs must meet a list of basic characteristics, which must

also be considered for their planning and elaboration. Audino and Nascimento (2010), after extensive literature review, list a number of characteristics of the EOs, of which we highlight Self-consistency (not relying on another EO to make sense); Customisation (from the fact that the EOs are independent, a teaching-learning process can use them in several different combinations, so that, on the whole, they fit the respective context); and Flexibility, where each EO contains a beginning, a middle and an end, which, together with the two characteristics mentioned above, makes possible its recombination in different contexts.

Science concepts often require a high degree of abstraction. Thus, computational resources and their corresponding possibilities of interaction assist in the process of elaboration of theories and also in the application of the knowledge acquired (Sá *et al.*, 2010). Also, the EOs enhance the interaction between students and teachers around learning a given content (Souza Jr and Lopes, 2007), which is one of the fundamental aspects of Gowin's teaching model.

Currently, video production is quite popular, especially among children and adolescents, and developed mostly for entertainment. However, there is still a great pedagogical potential to be explored (Vargas *et al.*, 2007). Proof of this is video sharing technologies, originally created for entertainment, but gaining popularity in academia (Snelson, 2008). In this context, we can say that audiovisual language is, among all the languages available for the web 2.0 and the blogosphere, very effective, in the sense of favouring greater social participation and expand the repercussion of events (Porto-Renó *et al.*, 2011). For example, on the *Youtube EDU* page, we can access content and channels from the largest universities and teaching and research centres, such as Stanford, MIT, Caltech, among others nationally and worldwide.

According to Rosa (2000), films have a great emotional appeal and can be motivating in the educational process. Compared to traditional text-based education, this type of approach helps many students learn better by being subjected to visual and sound stimuli (Mattar, 2009). This justifies the increased demand for didactic materials in the form of videos and the emergence of companies specialised in the production of this type of material – which does not necessarily guarantee the quality of educational objects produced (Gomes, 2008).

In the specific case of physics teaching, there are interesting initiatives regarding the production of short videos, based on structuring themes proposed in the PCN+ and BNCC itineraries, focusing on the teaching of mechanics and electromagnetism that the students themselves carried out as an activity, as an alternative strategy for the physics laboratory at the high-school level (Pereira & Barros, 2010; Pereira *et al.*, 2012). According to Pereira *et al.*, one of the advantages of this strategy, when compared to the traditional laboratory, is the responsibility the students must assume, as the videos will be watched “by other people,” which requires them to research more and understand better the main concepts. So, the strategy going beyond the production of conventional reports and enable students to explore – in the process of preparing the videos – other elements of culture with imagination and creativity (Pereira *et al.*, 2012). Moreover, the increased production

of videos on channels such as Youtube has led to the search for quality criteria to support the choice of materials to be used by teachers (Kulgemeyer & Peters, 2016).

STATE OF THE ART RESEARCH - VIDEOS IN PHYSICS TEACHING

Initially, we searched the literature for articles related to ICT-mediated MCP teaching. For this, we consulted four journals, in view of free access and relevance to the Brazilian physics teaching community: *Caderno Brasileiro de Ensino de Física* (CBEF), *Revista Brasileira de Ensino de Física* (RBEF), *Revista Novas Tecnologias na Educação* (RENTE) and *Informática na Educação: teoria e prática*. Thus, we divided our research into two axes: Teaching Modern and Contemporary Physics, and Production/Use of Videos in Physics Teaching. We focused on the titles of the articles and their keywords that contained the following representative terms: video analysis, video production, quantum physics, modern physics, restricted relativity, special relativity, particle physics, modern physics, and modern physics in high school. To specifically analyse the application of the MCP in teaching, we examined the issues published in the last years of each journal.

From the axes chosen, we constructed Tables 2, 3, 4 and 5, to present a quantitative overview of the presence of the topics of interest in the literature.

Table 2

Number of articles on MCP in CBEF (Authors, 2020)

CBEF	Works of interest	Total Articles
2017	9	48
2018	4	44
2019	8	39

Table 3

Number of articles on MCP in RBEF (Authors, 2020)

RBEF	Works of interest	Total Articles
2017	1	106
2018	0	126
2019	0	132

Table 4

Number of articles on MCP in RENTE (Authors, 2020)

RENTE	Works of interest	Total Articles
2017	0	108
2018	0	146
2019	0	135

Table 5*Number of articles on MCP in Informática na Educação: teoria e prática (Authors, 2020)*

Informática na Educação: teoria e prática	Works of interest	Total Articles
2017	0	58
2018	0	31
2019	0	36

Besides this survey, we also aimed to analyse the production and use of videos in physics teaching. In this way, we constructed tables 6, 7, 8 and 9.

Table 6*Number of articles on the use of videos in physics teaching in CBEF (Authors, 2020)*

CBEF	Works of interest	Total Articles
2017	5	48
2018	2	44
2019	1	39

Table 7*Number of articles on the use of videos in physics teaching in RBEF (Authors, 2020)*

RBEF	Works of interest	Total Articles
2017	0	106
2018	1	126
2019	1	132

Table 8*Number of articles on the use of videos in physics teaching in RENOTE (Authors, 2020)*

RENOTE	Works of interest	Total Articles
2017	3	108
2018	4	146
2019	10	135

Table 9*Number of articles on the use of videos in physics teaching in Informática na Educação: teoria e prática (Authors, 2020)*

Informática na Educação: teoria e prática	Works of interest	Total Articles
2017	1	58
2018	2	31
2019	2	36

We can notice that, despite the importance of the theme and the broad emphasis given to it in the official documents, the amount of work on MCP in Brazil is still small. About the total number of papers, we emphasise that even journals in the area have not published a significant number of articles. In another note, although several articles address the MCP and some the use of videos, none combines the two axes. This finding also reinforces the relevance of the present study.

TEACHER EDUCATION AND ARTICULATION BETWEEN DEGREE AND POSTGRADUATE COURSES

Considering the shortage previously pointed out, we can see that the creation of didactic videos on MCP in Brazil is needed. In this context, our proposal seeks to promote the interaction of the teaching degree students with those of the postgraduate program, to combine elements related to the initial and continuing teacher education, in the light of research in physics teaching. This initiative fosters, in a highly collaborative environment, the integration of teaching and research work inspired by the commitment to build concrete alternatives to physics teaching. Thus, research, a specific component of the postgraduate studies, and teaching, a particular component of the undergraduate studies, “can walk together and be articulated to allow mutual creativity” (Cury, 2004).

There are currently several public policies and initiatives of interest groups aimed at valuing, training, and enhancing teaching, in an attempt to respond to society’s demands for higher quality education. We can mention programs such as the Programa Institucional de Bolsa de Iniciação à Docência - PIBID (Institutional Scholarship Program for Teaching Initiation), which presents among its objectives:

Insert the undergraduates in the daily life of public schools, providing them with opportunities to create and participate in methodological, technological, and teaching practices of innovative and interdisciplinary character that seek to overcome problems identified in the teaching-learning process. (PIBID, 2014)

Among the problems the community points out that affect the science teaching, especially physics teaching, are difficulties related to the lack of didactic laboratories and experimental disciplines (SBF, 2005) and training of teachers to use innovative educational technologies that can have a significant impact on the classroom (Macêdo *et al.*, 2014). In this regard, we highlight the criticism that indicates the gap between the transfer of research in the areas of science teaching and the classroom (Menezes, 2009). In response to this gap between the academia (represented mainly by universities) and schools, a meaningful initiative was the creation of professional master’s programmes focusing on “products of an educational nature, aimed at improving teaching” (Moreira & Nardi, 2009). In this line, in the last decade, the Brazilian Society of Physics proposed the National Professional Master’s Programme in Physics Teaching (MNPEF).

We also highlight the importance and encouragement of the integration between undergraduate, postgraduate and basic education schools which are part of the growing initiatives in which there is an articulation between the preservice teachers (the undergraduates), university professors-researchers and teachers who work in the classroom at the basic level. This refers to an approximation between the various levels of education in a movement that combines research in teaching, initial and continuing teacher education and reflective production that has more direct implications and is attuned to the day-to-day life of the classroom and school life. The video production project on MCP that we have developed also presents this “fruitfulness of collective work” which, in turn, refers to “teaching as a passionate challenge,” alluding to what was exposed by Vilches and Gil-Pérez (2012). The interactional character of the research carried out in a postgraduate programme (PPG) and a physics teaching degree course is one of the aspects that appear in the guidelines to the PPGs in the current four-year evaluation period (2017-2020), as a way to foster the impact and relevance of the PPGs of the education area (46 Capes) in society:

(...) it is the task of the postgraduate programmes in the area to think and develop actions that contribute to reducing the gap between the research carried out in the postgraduate programme and the teaching carried out in the educational context, especially in basic education. Therefore, it is expected that actions and projects developed in postgraduate programmes in the area aim at transforming the practice of teachers, relying for this on the constitution of the teacher as a researcher, including a researcher of his/her own practice. In this way, with adequate and consistent training, it is expected that the graduates of the courses are also agents that contribute to the important social impact concerning the quality of education in school institutions, in their diversity. (Brasil, 2019)

The articulation undergraduation – postgraduation that we have carried out takes place within the physics teaching degree course of a public university that also has a professional master’s course in science teaching. The professors of the undergraduate course and the professors of the master’s program seek to coordinate their actions to involve the undergraduate and postgraduate students in joint projects, focused on the discussion of science education and the construction of intervention proposals that are in tune with the reality of the classroom. Hence, it is common to have projects that integrate work from undergraduate and master’s courses, inspired by lines of research developed by the professors-researchers of the institution. In the case of the videos presented here, we started from the premise of the importance of teaching the MCP in high school. We organised a working group involving several undergraduate students who attend a compulsory discipline, “Projetos de Ensino de Física Moderna” (Projects for the Modern Physics Teaching) and students of the professional master’s programme, in which there is a line of research called “Mediações por TIC no Ensino de Ciências e Matemática” (Mediations by ICT in the Teaching of Sciences and Mathematics) and theoretical and experimental disciplines on modern physics. In that university, there is a

laboratory dedicated to MCP teaching, where it is possible to carry out several classical experiments of modern physics. Its estimated cost is R\$2,000,000.00, and it was built between 2011 and 2014 with the university's resources. The students have access to all equipment and classes are organised around investigative activities: each student or group of students must perform the experiments (to get familiar with the basic concepts), obtain numerical data and analyse them in the light of literature - which is common in similar disciplines that integrate the higher education curricula. We understand that conducting the experiments is fundamental for the undergraduates to have contact with those advanced physics contents, given the ever-present demand for them to be taught at the high school level. However, we always draw their attention to reality: laboratories of this level are not available in basic schools. In this sense, we point at how important it is that students develop "solutions" so that the contents learned in the subject can be addressed in the schools with which they relate (due to compulsory curricular preservice training and PIBID projects, for example). In this sense, we ask students to make the necessary articulations so that the teaching of modern physics (the experiments they carry out in the undergraduate discipline) happens in basic school (given the school reality they studied and experienced). The presence of postgraduate students enhances the process, because it puts on the scene the possibility of developing more robust and longer research works (given that there is more time available for conducting a master's dissertation than, for example, for a semester laboratory discipline). Thus, from these intersections between our classroom practice and our scientific research interests, in view of the picture revealed by our state-of-the-art research, we developed an innovative line of research, namely, the development of videos containing MCP content for use in the classroom, especially in high school.

THE VIDEOS PRODUCED

To produce the videos, we followed the production process suggested by Kindem and Musburger (1997), which, basically, consists of three stages:

- Pre-production: planning of the material and elaboration of a script.
- Production: recording.
- Post-production: at this stage, all filmed parts are organised in such a way that the final product is consistent with the script.

Also, the structure of the videos also includes three parts:

- Part 1: presentation of the experiment that will be addressed in the video and availability of the list of materials necessary to execute it.
- Part 2: demonstration of the procedures needed to carry out the activity.
- Part 3: the didactic explanation of the phenomenon observed with the experiment or practical demonstration.

In these stages of discussions for the planning, execution, and application of the videos, the aspects laid out in Gowin's triad (Moreira, 2011) were contemplated. According to it, the sharing of meanings between teachers and students should also include the preparation of the teaching material, in this case, the videos, so that they are means that provide these negotiations of meanings. This triad appeared later, when they were used to mediate the themes with high-school and higher-education students.

All videos developed in the disciplines are available on *Youtube*, on the channel entitled "Ciência Curiosa" (Curious Science) (<https://www.youtube.com/user/Cienciacuriosa>), and on the site www.cienciacuriosa.com.br. The channel and the site are part of the product of the professional master's degree of one of the authors of this work. The importance of the development of the educational product here can also be considered in the objectives of a PPG, since, according to the coordination of the teaching area of Capes, in the document of the area:

The teaching area understands as an educational product the result of a creative process generated from a research activity, intending to answer a question or a problem or even a concrete need associated with the field of professional practice, which may be a real or virtual artefact or even a process. It can be produced individually (student or teacher) or collectively. The presentation of description and technical specifications contributes to the product or process being shareable or registered. (Brasil, 2019)

Since the videos are available on the Internet, physics teachers and students can use them as a complement to their studies and also as complementary material to their teaching practices. The materials are available to anyone who has access to the Internet, being characterised and licensed as Open Educational Resources (OER) (Unesco, 2011), which allows the community to reuse, remix, review, and redistribute them, thus stimulating their appropriation and ensuring that the fruits of the research actually reach school.

We also emphasise that students' independent production of videos is a possibility of innovation and an exercise of autonomy, as it represents an interesting and feasible proposal to overcome exclusively traditional teaching, in which students are used to one-way communication (Pereira & Barros, 2010).

Given the above panorama, several videos were produced, including various subjects related to science, in general, and physics, in particular, eleven of which concern modern and contemporary physics, whose titles we list below:

- Experiment with spectral lamps;
- Millikan's experiment;
- Electron diffraction experiment;
- Electron charge/mass experiment;

- Experiment with the photoelectric effect;
- Determination of Planck constant with LEDs;
- Franck-Hertz experiment;
- Production of nanoparticles;
- Double slit experiment with light;
- Experiment with the wave tank;
- Sound wave interference;

All videos are accessible at <https://www.youtube.com/playlist?list=PL313CF7A2A687D4AC>

The last three experiments listed, although not specific content of the MCP, have their insertion justified by making a bridge between classical physics and the regime of quantum physics, which makes them important for the didactic transposition of the MCP to high school and early grades of higher education.

Licensing of videos

To produce widely accessible materials, we chose a license called CC BY, from *Creative Commons* (2014), which allows the sharing and adaptation of the content, i.e., it is possible to copy, redistribute, remix, transform, and recreate, from the original material. This is a possible assignment for videos posted on *Youtube*. By this license, copyright is retained, and other users may reuse the work (Google, 2014).

RESULTS AND DISCUSSION

An element to evaluate the importance of this work to produce MCP videos in Portuguese and prove their validity is based on the use of search engines (search programs designed to search for keywords in documents hosted on the Internet). For the videos already made available, we selected some keywords, which would probably be the same students and teachers would use to analyse these topics on the Internet. Through them, we found a ranking attributed to each material. *Google* is the most popular search engine among Brazilians, having reached 94% of users' preference in 2013 (Serasa Experian, 2014) and, for this reason, was selected as the default search engine. As an auxiliary measure, the *Youtube* search engine was used, which, although it is part of *Google*, has its own indexing and search system. Besides the popularity factor, these systems present an approximate value of results of the total accesses, which was used to compare the order of preference that the videos achieved, with respect to similar materials. Other

search engines such as *Yahoo*, *Ask*, and *Bing* were not used in this assessment because their percentage of use was relatively low (Serasa Experian, 2014).

Below, we highlight some of the videos. For this, we elaborated tables from 10 to 16, containing the name of the experiment, the total number of views (number of hits) corresponding, the keywords used in the search and the posting date of the video. Also, we present the ranking of each video in the search engines and the total number of results obtained in the search when using *Google Videos* and *Youtube*. This stage of the research was carried out between February 15 and 25, 2020.

Table 10

Ranking and total accesses of the video referring to the experiment with spectral lamps (Total accesses: 3,952, Publication Date: 26/06/2013).

Search Terms	Google Ranking	Total Google	Youtube Ranking	Total Youtube
Spectral Lamps	1st	1,240	1st	113
Experiment with Spectral Lamps	1st	192	1st	4,930

Table 11

Ranking and total accesses of the video referring to Millikan's experiment (Total accesses: 20,603, Publication Date: 25/08/2013).

Search Terms	Google Ranking	Total Google	Youtube Ranking	Total Youtube
Millikan's Experiment	3 rd	3,560	4th	2,240
Millikan's Oil Drops	1 st	3.06	2nd	515

Table 12

Ranking and total accesses of the video referring to the electron diffraction experiment (Total accesses: 14,114, Publication Date: 02/07/2013).

Search Terms	Google Ranking	Total Google	Youtube Ranking	Total Youtube
Electron Diffraction	1st	1,110	1st	407

Table 13

Ranking and total accesses of the video referring to the load/mass experiment (Total accesses: 6,930, Publication Date: 24/12/2013).

Search Terms	Google Ranking	Total Google	Youtube Ranking	Total Youtube
Load/Mass Experiment	1st	190,000	1st	10,200
Electron Load/Mass	1st	41,700	2nd	1,220

Table 14

Ranking and total accesses of the video referring to the experiment with the wave tank (Total accesses: 8,228, Publication Date: 14/03/2014).

Search Terms	Google Ranking	Total Google	Youtube Ranking	Total Youtube
Wave Tank	2nd	71,900	2nd	29,700

Table 15

Ranking and total accesses of the video referring to double slit experiment (Total accesses: 19,622, Publication Date: 18/03/2014).

Search Terms	Google Ranking	Total Google	Youtube Ranking	Total Youtube
Double Slit Experiment	12 th	6,340	12 th	2,220
Young's Experiment	6 th	246,000	27 th	19,700

Table 16

Ranking and total accesses of the video referring to the nanoparticle production experiment (Total accesses: 2,055, Publication Date: 25/03/2014).

Search Terms	Google Ranking	Total Google	Youtube Ranking	Total Youtube
Production of Nanoparticles	1st	4,140	2nd	174

Considering the state-of-the-art research presented in tables from 2 to 9, we demonstrated the lack, in Brazil, of materials in video format addressing MCP themes elaborated in a systematic manner and in resonance with research in teaching. In this work, we present a proposal, based on the articulation between undergraduate and postgraduate studies, focused on the production of didactic videos in Portuguese that are at a time scientifically rigorous and able to arouse the interest of the public. In this sense, from the results presented in tables 10 to 16, it is evident that the videos produced by us have a strong appeal to the community because, since their posting, they have attracted a large audience when compared to similar materials. This aspect denotes that the sharing of meanings between those who access the materials (teachers and students) points to the pedagogical concepts that guided the idea of the videos, provided for in Gowin's triad (Moreira, 2011). This aspect also emerges as a differential of this set of videos exposed in this work - unlike quite interesting initiatives available on the *web*, although designed voluntarily or based on common sense.

It is also interesting to note that over the months and years, the number of accesses to our videos has increased considerably, which is an important indicator of at least a latent need. We believe that this demand finds a counterpart in the materials we have prepared because the videos combine the scientific rigour we mentioned before with an accessible and captivating language. In this regard, we highlight a representative and revealing data, when considering as an example, the video on the Load/Mass Experiment. In a more current search, carried out on February 19, 2020, the material we developed, originally

posted on 24/12/2013 (Table 13), had more than six thousand hits, occupying the first position in the *Google* ranking. In this same search, a promotional video, originally posted on 20/09/2011, developed by the specialised manufacturer of the equipment (the same one we used to create our video), occupied the fifth place, with 800 hits. Our video, although posted more than two years later, has been much more widespread, even considering the total time of this video (10min17s), which is more than twice that produced by the company (4min54s). Therefore, we understand that the articulation that we propose and carry out between undergraduate and postgraduate students is fundamental, based on a tripod that combines: scientific training, research in teaching, and commitment to the school.

In this context, it is imperative to create conditions for the formation of professionals capable of establishing the necessary didactic transposition (DT) of scientific knowledge (Chevallard, 1997). The DT is a set of transformations that relate the “wise knowledge” (produced by scientists), “knowledge to teach” (contained in materials and textbooks) and “knowledge taught” (mediated by the teacher’s work, is produced in the classroom). This process is not a mere simplification, but rather the production of knowledge capable of connecting two different epistemological domains: science and classroom. Hence the challenge of promoting the updating and modernisation of knowledge, given the need to introduce the contents of modern theories in physics curricula (Brockington & Pietrocola, 2005; Coimbra, 2016). Therefore, our work is based on the conception of the curriculum as a living element, with which and on which the teacher acts, updating it and transforming it into concrete classes, rich in content and interesting. This inspiration also guided the elaboration of the videos, because they were designed to be used as educational objects compatible with the teaching time of high school classes, but also as sources of consultation outside the classroom. The videos can be used individually, but considered together, they constitute an organic whole that aims to cover a wide spectrum of MCP themes by providing the negotiations of meanings between teachers and students, mediated by teaching materials.

Considering the formation of students participating in the project, we encourage the reading of scientific articles related to each topic addressed and place emphasis on the performance of each experiment, a practice mediated by the materials and equipment available in the didactic laboratory of modern physics. In the process, the students experience difficulties and deadlocks inherent to the experimental activities (some of the experiments require several weeks to be completed), elements that play a significant role in the development of knowledge by students, and reflect in the scripts of the videos. Also, students can deepen the connections between contents addressed in the curricular disciplines of MCP and those related to the field of teaching. The works culminate in the production of the videos and their use in the classroom.

Regarding the video on “production of nanoparticles,” we call attention to the possibilities associated with the didactic transposition in a movement that brings us closer to the *locus* of the “wise knowledge”: the research laboratory. This is about crossing the boundaries of the didactic laboratory and entering a space in which cutting-edge scientific research is carried out – in this specific case, the production of nanoparticles

through laser ablation. In Table 16, we have evidence of the demand for materials of this type. And here we highlight that this material has served as a basis, for example, for various interventions in the classroom, both at the postgraduate level (professional master's dissertations) and undergraduate level (course completion papers), in order to investigate means of producing didactic sequences on topics such as "nanosciences" and "nanotechnology," as well as to evaluate their consequences and their impact in the classroom, in view of the teaching-learning processes. This initiative is therefore in line with modern proposals to bring undergraduate students closer to current research topics and research laboratories (Melo Jr. *et al.*, 2012; Sievers *et al.*, 2013). Even funding agencies, such as CNPq, have encouraged scientists to disseminate their research work to promote scientific dissemination and popularisation of science. (CNPq, 2008). Therefore, we propose to strengthen ties between researchers and students involved in research laboratories (where "wise knowledge" is produced) and researchers, students, and teachers who work directly with the teaching of sciences – and that has a direct relationship with the daily life of schools – to promote the didactic transposition and the production of teaching and dissemination materials, especially those related to the MCP. Thus, we envision the creation of multidisciplinary projects in which researchers, professors, undergraduate, and postgraduate students transit, establishing more and better connections between the spaces of laboratories and classrooms.

By freely making videos available on the Internet, students, teachers, and those interested in the subject can access them without further restrictions. This is a fundamental characteristic of educational objects licensed as an OER, as it allows virtually infinite reuse and sharing with the entire community of the educational environment – which implies dissemination on a larger scale than that achieved by other materials, such as articles disseminated in events and even scientific dissemination journals. In this regard, it is important to highlight the difficulties observed – in Brazil – of access to didactic laboratories, especially those related to MCP, and even to good quality and widely accessible didactic materials in Portuguese on the theme.

We would also like to note that, although this project is organically related to the Brazilian school reality, the portal where the videos are found also receives frequent visits from people from various parts of the globe such as Portugal, the Netherlands, the USA, Uruguay, France, Australia, Angola, the United Kingdom, Belgium, Slovakia, Italy, and Saudi Arabia, to name only the largest numbers of access.

CLASSROOM APPLICATION

For effective learning, it is essential that the use of a video is followed by two steps: first, teachers need to assess understanding by asking questions and giving students the opportunity to ask questions on their own; second, teachers must prepare tasks that challenge their students with problems that need the information explained in the video (Kulgemeyer & Peters, 2016). Then, to deepen and validate the use of the videos, didactic sequences were elaborated to be used with high school students and applied in

the classroom. This initiative gave rise to the product of a second professional master's degree. To compare responses and gather perceptions (which were analysed later) the teacher used the field diary and the questionnaires applied throughout the process.

In the first subject worked – spectral lamps - the teacher made a *slide show* and used the video referring to the experiment in sequence, stopping the video when necessary to complement or highlight more relevant information. At first, the main advantages of the video were observed: it can be paused and restarted from any point, ensuring that the information can be revisited when anyone involved in the process wishes. Therefore, after interacting with the class, the videos themselves answered the teacher's questions. Among the central students' considerations, we highlight the fact that the material is developed by specialists, in this case, undergraduates guided by university professors. At the same time that difficulties arise due to the language adopted, it is essential to contact young people with a more elaborate scientific language.

Subsequently, in a second meeting, Millikan's experiment was presented to students with the aid of the video. The task consisted of, after watching the video, listing the possible questions that would be answered by the teacher. The objective of this approach was to arouse the student's desire to seek relevant information on the subject (Santos, 2017). The students' main questions were linked to the main differences of working with the video itself and, effectively, performing the experiment in the laboratory.

In fact, one of the difficulties encountered by teachers who try to explain experiments with images of books or handouts is precisely that the schemes presented, in many cases, function as illustrations, far from the actual assembly of the apparatuses (Reis; Martins, 2015). Therefore, when addressing the photoelectric effect in an expository class, the teacher used the videos to present the experiment and highlight the assembly as well as its execution, bringing the experience closer and making it more tangible for students.

In this stage of application in the classroom, among the most relevant considerations on the use of the audiovisual resource is the importance of the "visual" part that makes the experiment more understandable, according to the students. The fact that the videos mention the historical impact of the experiments and their applications in everyday life is also highlighted as positive. Among the negative considerations, the most outstanding fact is that students do not experiment themselves in the laboratory, underscoring the impression that handling would further assist in understanding the phenomena worked. Nevertheless, the availability of the videos contributed to the creation of more dynamic and interesting classes in the opinion of all students, which again points to the evidence of negotiation of meanings provided for in Gowin's triad.

CONCLUSIONS

Beyond the significant numbers of accesses and the great receptivity achieved by the videos we have produced, we must point out that they can serve as reference

and consultation material for teachers and students while being a vehicle for scientific dissemination.

Although the videos do not allow interaction comparable to experimental situations in the real laboratory, they can assist teachers who have had little (or no) contact with the experiments addressed, and also to students who intend to expand and deepen knowledge. Also, the videos function as essential dissemination and advertising tool of the physics teaching degree course, which can stimulate the entry of younger people into teaching and research careers.

It is important to note that at no time videos replace the work of a teacher in the teaching and learning process. However, they appear as auxiliary objects to the extent that the educational resources present in primary school are, in some cases, extremely precarious.

We also emphasise that the videos elaborated in this project may be useful to the professional masters' courses in natural sciences teaching, especially those structured in a network, such as the MNPEF of SBF. Both the videos produced and the very idea of making them can serve as sources of consultation and also inspiration, given the character of continuing education of the master's students. Also, we understand that investigating why the audience aroused by these videos is so large may be a relevant contribution to the area.

Currently, video production continues and the materials developed have served as the basis for class preparation at the university and in schools in which students linked to the project work. Also, teacher education courses have been developed based on videos and accumulated experience in their development. From these experiences, videos can go through new editing processes to make them better suited to certain needs. We believe that, in a context in which this type of production is generally related to large universities and large centres, this work, developed in a medium-sized public university, is a critical contribution to the teaching of MCP in our country.

AUTHORSHIP CONTRIBUTION STATEMENTS

AGBJr conceived the initial idea of the elaboration of the videos and made them available on the WWW. SAHC filmed, interviewed, and edited the videos and, at the end of the edition, also made them available on their website. JAL was, from the beginning of the physics course, the professor of the Modern Physics Laboratory discipline of the physics course and accompanied MVP in the assembly of the experiments so that SAHC could film them, helping to finalise the written work. NCSF was a master's advisor at PPGFCET SAHC and assisted the group with writing much of the article. MVP conducted the survey of the number of accesses to the videos and compiled the data. TVS wrote a part of the work, adding data after she used the videos at school and made visits with the students to the teaching and research laboratories at university. Therefore, all authors

contributed harmoniously to the gradual assembly of the work and all assisted punctually, until reaching its final construction.

DATA AVAILABILITY STATEMENT

We declare that the data supporting the results of this study are openly available at: <http://repositorio.utfpr.edu.br/jspui/handle/1/2809>; <http://repositorio.utfpr.edu.br/jspui/handle/1/1922> e em <http://repositorio.utfpr.edu.br/jspui/handle/1/1029>. To produce widely accessible materials, we chose a license called CC BY, from *Creative Commons* (2014), which allows the sharing and adaptation of the content, i.e., it is possible to copy, redistribute, remix, transform, and recreate, from the original material.

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