# An immersive learning environment on the introduction of power generation systems for pre-service teachers of early childhood education

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**ABSTRACT**

*Virtual environments offer innovative and promising solutions for natural science education, benefiting both students and teachers. Research indicates that pre-service teachers struggle to visualize and describe power generation processes, potentially passing on alternative conceptions to students. This study focuses on the design, development, and evaluation of a 3D virtual reality learning environment for large-scale power generation systems, specifically steam power plants. Following an "innovative" teaching framework, the study aimed to explore and reconstruct pre-service teachers' conceptions through interaction with the immersive virtual environment. The research procedure involved four parts of a semi-structured interview with pre-service teachers exploring their ideas and whose analysis results confirm existing literature on alternative conceptions. The study highlighted cognitive progress, especially in the technological dimension of power generation systems using the virtual reality learning environment.*

**KEYWORDS**

*Power generation systems, virtual reality, immersive learning environment, pre-service teachers' conceptions*

**RÉSUMÉ**

*Les environnements virtuels offrent des solutions innovantes et prometteuses pour l'éducation en sciences de la nature, bénéficiant à la fois aux élèves et aux enseignants. Des recherches indiquent que les enseignants en formation initiale ont du mal à visualiser et à décrire les processus de production d'énergie, transmettant potentiellement des idées fausses aux élèves. Cette étude se concentre sur la conception, le développement et l'évaluation d'un environnement d'apprentissage en réalité virtuelle en 3D pour les systèmes de production d'énergie à grande échelle, en particulier les centrales électriques à vapeur. En suivant un cadre d'enseignement "innovant", l'étude visait à explorer et à reconstruire les représentations mentales des enseignants en formation initiale grâce à l'interaction avec l'environnement virtuel immersif. La procédure de recherche comprenait quatre parties d'un entretien semi-structuré avec des enseignants en formation initiale explorant leurs idées et dont les résultats de l'analyse confirment la littérature existante sur les représentations mentales alternatives. L'étude a a mise en évidence des progrès cognitifs, en particulier dans la dimension* *technologique des systèmes de production d'énergie grâce à l'environnement d'apprentissage en réalité virtuelle.*

**MOTS-CLÉS**
*Systèmes de production d'énergie, réalité virtuelle, environnement d'apprentissage immersif, conceptions d'enseignants en formation initiale*

## INTRODUCTION

Modern ICT (Information and Communication Technologies) offer supplementary support for teachers and students. Virtual Reality (VR) is a computer-generated three-dimensional simulation that fully immerses users, allowing real-time interaction with virtual objects. It is successfully integrated into teaching natural sciences, providing immersive contact with virtual spaces such as physics labs and enhancing experiential learning (Di Natale et al., 2020). Due to its immersive, interactive, and engaging characteristics it serves as an engaging and motivating tool.

The knowledge of pre-service teachers regarding scientific issues, such large-scale power generation systems and energy, hold significance for both their personal decisions and their future profession as educators (Bower et al., 2020). Pre-service teachers play a crucial role in the adoption of technology since their preparation, knowledge, abilities, and perspectives have the most lasting influence and potential to drive change (Liu et al., 2023; Metzler & Woessmann, 2010). Developing well-designed teacher education, could have a profound impact on their future professional practices and, consequently, on student learning outcomes (Faliagka et al., 2016).

Understanding how power generation systems work and the concept of energy, is vital for science education, as it provides a powerful framework for comprehending natural and technological processes. A solid grasp of its fundamental principles is crucial for tackling energy supply challenges in modern societies. Students observe and describe energy-related processes using core aspects of energy. However, being an abstract concept, energy requires careful conceptualization. Research on energy learning among students is extensive, but limited studies explore pre-service and in-service teachers' learning and teaching aspects (Chen et al., 2014). Thus, this study aims to explore the impact of a virtual learning environment concerning large-scale power generation systems, like steam power plants on pre-service teachers of early childhood education.

## THEORETICAL FRAMEWORK

Pre-existing conceptions[1] can impact learning experiences and receptivity to new ideas in the context of science education (Kambouri-Danos et al., 2019). When these conceptions align with correct scientific views, they can serve as a foundation for conceptual understanding. However, persistent alternative conceptions, which are inconsistent with accepted scientific knowledge, can act as obstacles to effective learning.

Both teachers and students may find it challenging to overcome deeply ingrained alternative conceptions, especially if these conceptions have persisted for a long time. Teachers'

[1] For the French-speaking readers we would like to clarify that the term "conception" which comes from the Anglo-Saxon tradition of science education corresponds to the term "représentation mentale" which is mainly used in the French-speaking tradition (Orange & Orange Ravachol, 2013). A detailed analysis of the content of this term is beyond the scope of this text.

conceptual understanding of specific topics may not always match their conceptions of teaching difficulties in those areas (Gunstone et al., 2008). Inadequate attention to complex concepts, even in undergraduate physics programs, can lead to teachers' limited understanding and difficulties in effectively teaching those concepts (Hussain et al., 2012). Traditional teaching methods often fall short in correcting students' alternative conceptions, emphasizing the necessity for additional efforts in teaching and learning activities to tackle these issues.

This study's theoretical framework focuses on school knowledge about large-scale power generation systems operation, encompassing three conceptual dimensions: phenomenological, technological, and scientific (Sissamperi & Koliopoulos, 2015).

1. The phenomenological dimension defines the characteristics of technological systems like the steam power plant, identifying and describing their external features.
2. The technological dimension involves distinguishing the different parts of the systems, explaining their structure and operation. Three-dimensional representational models in the VR environment aid in understanding power generation systems' structure and operation.
3. The scientific dimension involves the qualitative conceptual model of energy chains which contains the qualities of energy storage, transfer, and transformation (Koliopoulos & Meli, 2022). This model is known to be effective for both young children and teachers in preschool and primary education, as it has been applied to simple small-scale energy systems described qualitatively (Delegkos & Koliopoulos, 2020; Koliopoulos & Argyropoulou, 2012), and even more complex systems like steam power plants (Sissamperi & Koliopoulos, 2015, 2021; Stavropoulos & Koliopoulos, 2019).

Natural sciences rely on experimentation, making laboratory work and innovative approaches vital for researchers and educators. Computer-based simulations have long been utilized in education, offering well-known advantages. VR, especially in simulations, can complement traditional teaching, providing unique experiences and access to distant or costly lab resources. Research confirms that VR captures students' attention and excitement, enabling them to interact with and create 3D worlds and allows for accurate depiction and close examination of certain characteristics (Bailenson et al., 2008).

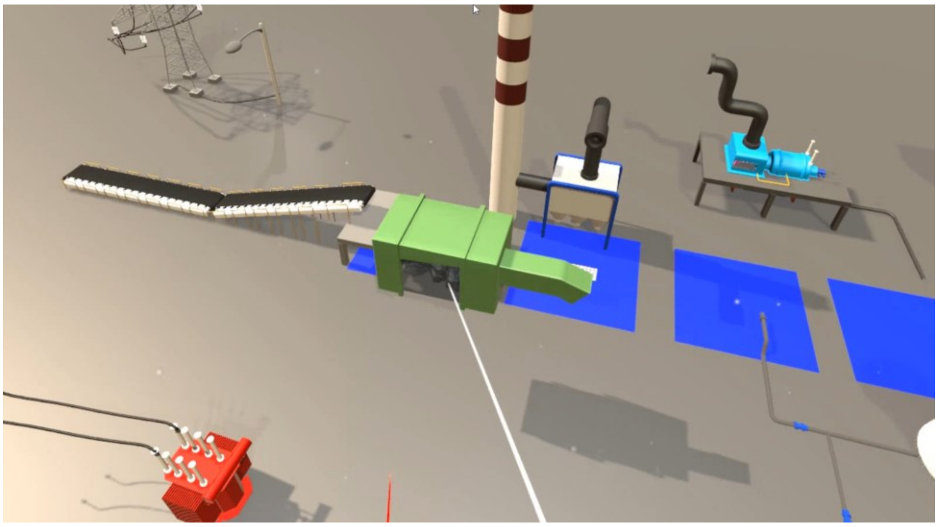
Considering that this research aims to explore and investigate the conceptions regarding a steam power plant, the following research questions (RQ) were proposed to investigate the topic further:

- RQ1. What are the pre-existing conceptions of pre-service teacher of early childhood education about steam power plants?
- RQ2. How were the participants' conceptions modified during and after the use of a VR learning environment concerning the different parts and function of a steam power plant model?

A custom VR application was developed using 'Unity3d' and 'Autodesk 3ds Max' to support an interactive learning experience. The VR approach utilizes a digitally-created environment to replicate real-life interactions with a system (Here, a steam power plant model - Figure 1). By integrating various technologies, users can engage with the virtual scenario in a multi-sensory way. Compared to conventional learning and training methods, the VR system offers a wide range of advantages as it enables training through a hands-on, learning-by-doing approach (Choi et al., 2015).

**FIGURE 1**

*A view of the VR learning environment showing specific parts of the steam power plant model*



## METHODOLOGY

### *Sample*

The sample consisted of seven female pre-service teachers, pursuing undergraduate studies in the Department of Education Sciences and Early Childhood Education of the University of Patras. None of the participants declared the existence of significant previous experience using VR, either for entertainment or for educational purposes. Therefore, the sample is considered to consist of novice VR users. All participants had attended lectures on the concept of energy within a course during their 3rd year of studies.

### *Research procedure*

The research procedure involved four parts of a semi-structured interview. Parts A and B contained questions exploring participants' energy and power generation systems conceptions. Part A showed a real steam power plant photo, asking about its parts and functions. Part B used VR to present the power plant's parts, allowing inspection and discussion. Part C involved interactive tasks, arranging parts for a lamp's lighting. In Part D, participants constructed the power plant's energy chain on paper. Table 1 includes the research procedure for addressing RQ1 & RQ2.

The VR learning environment was divided into two sections. In the first section (Part B of the interview), different components of the steam power plant were presented as 3D models in a random order. Participants could rotate and inspect each part for one minute, expressing their conceptions and describing their functionality as part of the system. The 3D components presented were: (1) coal hopper, (2) boiler, (3) turbine and electric generator, (4) alternator, (5) pylon, high voltage transmission cables, and a light lamp. After completing Part B, participants moved to the second section (Part C of the interview), interacting with the virtual 3D models. They had to place the parts in the correct order to construct a valid energy chain inside the VR environment and turn on the light lamp. No feedback was given during their interaction unless they successfully constructed the chain.

**TABLE 1**
*Research procedure break-down*


| **PART A**<br>**Initial part of the interview** | **PART B**<br>**VR presentation of the plant's sub-systems** | **PART C**<br>**Interaction with the VR aiming to put the plant to function** | **PART D**<br>**Energy chain design** |
|---|---|---|---|
| For the steam energy plan, try answering the following "What do you see in the image? Do you know what it is? How is it named? What does it consist of? How does it work?" | For each 3d representation of the power plant's sub-systems try answering the following "What do you see in the image? Do you know what it is? How is it named? What does it consist of? How does it work?" | Interact with the objects in the VR environment and place them in the correct order to make the plant work (turn on the light lamp) | Please construct the steam power plant's energy chain |

## RESULTS

The initial interview responses (Part A) of each participant are summarized in Table 2, while Table 3 includes their corresponding answers during the three-dimensional VR presentation (Part B). In the initial interview (Part A), alternative conceptions about identifying the steam power plant and its subunits and operations were evident. Overall, there was a lack of coherent knowledge and understanding of the concept of energy and energy chains, as all answers were either phenomenological or tautological (Sissamperi & Koliopoulos, 2021).

**TABLE 2**
*Participants' responses about the steam power plant parts during the initial interview, using a photograph of the steam power plant's exterior (Part A)*

| Participant | How is it named? | What does it consist of? | How does it work? | Reference to energy storage | Reference to energy transfer | Reference to energy conversion |
|---|---|---|---|---|---|---|
| **P1** | Nuclear power plant | Nuclear Rector | The plant converts nuclear energy into electricity and transfers it. | Yes | Yes | Yes |
| **P2** | Nuclear power plant | - | Some form of energy or 'nuclear energy' is stored in the plant and transported to the environment through the chimneys. | Yes | Yes | Yes |

| | | | | | | |
|---|---|---|---|---|---|---|
| **P3** | Fuel processing plant | Chimneys, Machines, Central space, / Central area, Smokestacks, Pipes / Tubes | The process starts from the main section, which is connected to the chimneys through pipes, and the smoke is released. | No | No | No |
| **P4** | Nuclear power plant | - | Through electricity and heat, it generates energy (referring also to combustion | No | No | Yes |
| **P5** | Electricity plant | Transportation Rails, Main section, Chimneys | Through processing, it converts mineral resources into electric energy. | No | Yes | Yes |
| **P6** | Electric generation plant | Main Section, Chimney, Tanks (referred to as 'Large Cylindrical Cement' objects) | It takes the energy from the plant and transfers it to the cylinders (chimneys) that lead to smoke. In some way, they obtain air and sunlight and convert them. | No | No | Yes |
| **P7** | Power plant | "Chimney, loading ramp, Pipes, Burner (referred to as 'the thing that burns')" | It starts from the chimneys and the burner, the ramp is used to lift things, and somewhere in the middle of the process, combustion helps to produce electricity. | No | No | No |

During Part B, P3 and P7 initially omitted energy storage, transfer, and conversion. P7 confused electricity with electrical energy but recognized the power plant as an "energy generation plant." P4, P5, and P6 mentioned energy conversion but didn't address energy storage. P6 didn't grasp the linear chain concept, leading to an unclear understanding of input, output, and energy conversion stages. P2 and P4 mentioned the concept of energy but not "electrical energy." The three participants who referred to the station as a "nuclear power plant" during Part A didn't mention "electrical energy" in Part B.

**TABLE 3**

*Participants' example responses during interaction with the first section of the VR learning environment, inspecting each separate three-dimensional subpart (Part B)*

| | |
|---|---|
| **Coal Hopper** | "Contains lignite," "Contains mineral," "Contains fuel" (P1, P5, P6, P7)<br>"Melts the fuel," "Dissolves the rocks" (P3, P4, P5)<br>"Petroleum" (P3)<br>"Contains coal" (P7)<br>"Is a conductor" (P6)<br>"Is transformed into another form of energy" (P1)<br>"Works with heat" (P1) |
| **Boiler** | "It emits heat" (P1, P2, P4)<br>"There is combustion," "Burner" (P5, P6, P7) "Heat pump" (P1)<br>"Some liquid is present in the pipes" (P3)<br>"There is gas in the pipes,"<br>"There is smoke in the pipes" (P5, P7) |

| | |
|---|---|
| | "There is oil in the pipes" (P6)<br>"Fireplace" (P7)<br>"Something hot like lava" (P3)<br>"The stones generate some heat through friction" (P4) |
| **Turbine and Electric Generator** | "It stores energy" (P2, P3, P6)<br>"Gears" (P4, P5, P6)<br>"Electricity" (P1, P3)<br>"Pipes" (P2, P3, P6)<br>"It transfers energy" (P2, P3)<br>"Chimney," "Emits smoke" (P1, P4)<br>"Kinetic energy" (P7)<br>"It generates energy" (P4)<br>"Heat" (P2)<br>"Core" (P3)<br>"Vortex" (P5)<br>"Axle" (P7)<br>"Irrigation" (P6)<br>"Generator" (P6) |
| **Alternator** | "Transfers electrical current", "Transfers energy", "Transfers heat" (P5, P1, P7, P3)<br>"Resembles a radiator" (P1, P2, P7)<br>"Emits heat" (P1, P2, P6)<br>"Has multiple magnets" (P5)<br>"Uses some fuel" (P6)<br>"Battery" (P4)<br>"Produces electricity" (P4)<br>"It stores energy" (P4) |
| **Pylon, High Voltage Transmission Cables, and Lamp** | "Transfers energy", "Transfers electricity" (P1, P2, P3, P4, P6, P7)<br>"Telephone antenna" (P4, P5, P7)<br>"Tower" (P2, P5, P7)<br>"Electricity column" (P1, P2, P3, P5, P6)<br>"High voltage column" (P1)<br>"Core" (P3)<br>"Scaffold" (P2)<br>"The antenna generates electricity" (P4)<br>"Light energy" (P4) |

According to interview results using the VR environment, we may claim that conceptions regarding the technological dimension of knowledge have been sufficiently constructed. After part C, participants were able to identify and name the different parts and the majority of them (6 out of 7) expressed the functioning of the power plant as a chain of objects.

**TABLE 4**

*Participants' number of tries before successfully constructing the energy chain and making the lamp light up (Part C).*

| Participant | Unsuccessful tries | Comment |
|---|---|---|
| **P1** | 1 | In the first and unsuccessful attempt, the Transformer was placed immediately after the Boiler. The participant expressed doubts about the position where the bulb should be placed. |
| **P2** | 2 | Although the coal storage was mentioned as connected to the boiler, the participant placed them at positions 1 and 3 initially. Later, they moved the boiler to position 4 and tried to connect the coal storage to the turbine and generator subsystem. |
| **P3** | 1 | The pylon and the lamp were initially placed at the beginning, while the coal storage was placed at the end. The participant expressed their concerns and rearranged the placement. |

| | | |
|---|---|---|
| **P4** | 1 | Initially, the boiler was placed first, but the participant recognized that it should go before the burner, possibly for transporting lignite inside, referring to Part A interview. This marked a successful transition from the phenomenological to the technological dimension. |
| **P5** | 0 | The participant placed the parts successfully and described fully the energy chain. |
| **P6** | 1 | Although the coal storage was successfully placed in the first position, and the Boiler was connected to the turbine and the generator, the participant considered that another subsystem should be placed between them. While searching for a position to place the transformer, the participant revised and proceeded to rearrange the positions to successfully complete the energy chain in the virtual environment. |
| **P7** | 3 | "Turbine and Generator" have been placed in the end of the chain. In the second attempt, the participant correctly positioned them after the Boiler but didn't connect the transformer properly. They also tried to place the coal storage between the Boiler and the Turbine. |

In Part C, interview results show that while scientific knowledge was not fully acquired, all participants successfully placed the 3D models and described the system in the VR environment, including at least two forms of energy. Six out of seven participants named more than half of the parts of the electricity generation system (Table 4).

**TABLE 5**

*Description of participants' energy chains drawn on paper (Part D)*

| Participant | Description |
|---|---|
| **P1** | In the initial interview, only thermal energy was represented in the diagram, although chemical, thermal, and kinetic energy were referenced before. The turbine and generator were labeled as "blades and dynamo," and only mechanical and electrical work were included. |
| **P2** | The diagram showed chemical, thermal, and electrical energy, but kinetic energy and the term "work" were not mentioned. |
| **P3** | The diagram depicted chemical, thermal, kinetic, and electrical energy, with kinetic energy converted to electrical energy by the voltage transformer. |
| **P4** | The participant considered flow and system-environment interconnection in the diagram, but alternative conceptions were evident regarding the conversion of mechanical energy to electrical energy. |
| **P5** | Different energy conversions were evident, but the term "work" was not referenced at all. The conversion of energy to electricity was attributed to the transformer. |
| **P6** | It is not clear whether the participant can distinguish the concept of "work" from that of "energy," as the designed chain appears to start with mechanical "work" and end with thermal "energy". |
| **P7** | Conversion of energy was shown, and the term "work" was used, not mentioned in the previous part of the interview. The participant attributed the conversion of mechanical energy to electrical energy to the transformer, not the generator, which was labeled "Magnet" with "Water and Steam." |

No safe conclusion may be drawn regarding whether the participants have appropriated the energy chain model for describing and explaining the operation of the power plant. However, it is particularly encouraging that the number of participants who provided a phenomenological response (as compared to Part A) decreased to just one (Table 5).

## DISCUSSION

This study explored two main questions: (RQ1) pre-service teachers' conceptions about large-scale power generation systems, and (RQ2) the possibility of transforming alternative conceptions using a relevant VR environment. Even though there are existing proposals in the literature regarding pre-service teachers' and power generation systems, most of them focus on describing attitudes, values, and opinions rather than exploring scientific ideas (Cruz-Lorite et al., 2022). Studies on the impact of instructional activities related to power stations confirm that such learning experiences can positively influence students' reasoning and decision-making processes (Evren & Aycan, 2018).

As indicated by this study's results, participants' understanding of power stations and corresponding scientific concepts was initially inadequate. During Part A, they either ignored or had limited understanding of power generation systems, in terms of functionality and components. Although some mentioned the term "nuclear energy", they failed to connect it to electrical energy, power generation, or any other form of energy. All answers were phenomenological, and no participant could correctly name power generation system subsystems or describe their functionality, highlighting the existence of insufficient technological and scientific knowledge.

When participants interacted with 3D subsystems (part B of the research procedure), expressed assumptions about functionality. Conceptions evolved, resolving uncertainties from the initial questions (part A), and generating interest through VR immersion. One participant gave a complete explanation, five of them gave correct but incomplete ones, and only one expressed an alternative conception. Phenomenological answers decreased significantly from seven to one, highly significant given the short intervention duration.

Part C of the research procedure enabled interaction with the steam power plant. During interaction, participants visualized the different steam power plant's components and improved their understanding of the system consisting of interconnected parts. When asked about the light lamp's operation, 6 out of 7 participants correctly explained it as a chain of objects. Regarding the steam power plant's components, 3 out of 7 mentioned all subsystems, 3 mentioned three or four of them, and only one did not mention any. Based on these results, we may claim that participants committed the first steps of understanding the technological dimension of the power plant.

Considering the energy chains drawn on paper (Part D), it becomes evident that understanding of the technological dimension of knowledge led to an improvement of conceptions about the power plant and subsequently about the concept of energy. In that part, all participants that initially did not associate electrical energy with other forms, recorded at least two other forms of energy. Thus, we may claim that the technological dimension of knowledge, acquired via the VR learning environment, supported the transformation of participants' alternative concepts on power generation systems.

In conclusion, the findings of this study are in alignment with the current literature (Bailenson et al., 2008; Choi et al., 2015; Stavroulia & Lanitis, 2017), indicating that the utilization of VR has the potential to support the construction of coherent conceptions, particularly regarding the technological dimension of the knowledge about large-scale power generation systems. Through the conducted research procedure, it was verified that the designed VR learning environment based on linear causal reasoning (Tiberghien, 2004) and energy chains can transform pre-service teachers' conceptions with regards to the technological dimension of knowledge of large-scale power generation systems, such as the steam power plant, confirming VR environments as a prominent feature in educators' training (Ainge, 1997; Patle et al., 2018). An interesting topic for future investigation is the extent to which there is a correlation between the transformation of conceptions and participants' attitudes towards VR as a technological paradigm, as well as the content of the application. Further research and a larger sample are recommended to clarify the degree to which knowledge transformation occurs due to the use of a VR environment, as well as the way that such environments contribute to the construction of the scientific dimension of knowledge for pre-service teachers and validate it as a complete educational tool.

## REFERENCES

Ainge, D. (1997). Virtual Reality in schools: The need for teacher training. *Innovations in Education and Training International, 34*(2), 114-118.

Bailenson, J. N., Yee, N., Blascovich, J., Beall, A. C., Lundblad, N., & Jin, M. (2008). The use of immersive Virtual Reality in the learning Sciences: Digital transformations of teachers, students, and social context. *Journal of the Learning Sciences, 17*(1), 102-141.

Bower, M., DeWitt, D., & Lai, J. W. M. (2020). Reasons associated with preservice teachers' intention to use immersive virtual reality in education. *British Journal of Educational Technology, 51*(6), 2215-2233.

Chen, B., Eisenkraft, A., Fortus, D., Krajcik, Neumann, J. K., Nordine, J., & A. Scheff A. (2014). *Teaching and learning of energy in K – 12 Education*. New York: Springer.

Choi, S., Jung, K., & Noh, S. D. (2015). Virtual reality applications in manufacturing industries: Past research, present findings, and future directions. *Concurrent Engineering Research and Applications, 23*(1), 40-63

Cruz-Lorite, I. M., Cebrián-Robles, D., Acebal-Expósito, M. D. C., & Blanco-López, N. (2022). Pre-service teachers' ideas about obtaining electricity in nuclear power stations in a role play context. *Eurasia Journal of Mathematics, Science and Technology Education, 18*(11), em2176.

Delegkos, N., & Koliopoulos, D. (2018). Constructing the "Energy" concept and its social use by students of Primary Education in Greece. *Research in Science Education, 50*(2), 393-418.

Di Natale, A. F., Repetto, C., Riva, G., & Villani, D. (2020). Immersive virtual reality in K-12 and higher education: A 10-year systematic review of empirical research. *British Journal of Educational Technology, 51*(6), 2006-2033.

Evren, Y. A., & Aycan, U. (2018). Pre-service Science teachers' decisions and types of informal reasoning about the socioscientific issue of nuclear power plants. *Educational Policy Analysis and Strategic Research, 13*(1), 31-53.

Faliagka, E., Rigou, M., & Sirmakessis, S. (2016). Identifying great teachers through their online presence. In S. Casteleyn, P. Dolog & C. Pautasso (Eds), *Current Trends in Web Engineering* (pp. 71-79). Springer.

Gunstone, R., Mulhall, P., & McKittrick, B. (2008). Physics teachers' perceptions of the difficulty of teaching electricity. *Research in Science Education, 39*(4), 515-538.

Hussain, N. H., Latiff, L. A., & Yahaya, N. (2012). Alternative conception about open and short circuit concepts. *Procedia - Social and Behavioral Sciences, 56*, 466-473.

Kambouri-Danos, M., Ravanis, K., Jameau, A., & Boilevin, J.-M. (2019). Precursor models and early years Science learning: A case study related to the water state changes. *Early Childhood Education Journal, 47*(4), 475-488.

Koliopoulos, D., & Meli, K. (2022). *The teaching of energy. Epistemological and didactical dimensions.* University Studio Press [In Greek].

Koliopoulos, D., & Argyropoulou, M. (2012). Constructing qualitative energy concepts in a formal educational context with 6-7-year-old students. *Review of Science, Mathematics and ICT Education, 5*(1), 63-80.

Liu, X., Gao, W., & Chen, L. (2023). Does pre-service teacher preparation affect students' academic performance? Evidence from China. *Education Sciences, 13*(1), 69.

Metzler, J., & Woessmann, L. (2012). The impact of teacher subject knowledge on student achievement: Evidence from within-teacher within-student variation. *Journal of Development Economics, 99*(2), 486-496.

Orange, C., & Orange Ravachol, D. (2013). Le concept de représentation en didactique des sciences : Sa nécessaire composante épistémologique et ses conséquences. *Recherches en Éducation, 17*, 46-61.

Patle, D. S., Manca, D., Nazir, S., & Sharma, S. (2018). Operator training simulators in virtual reality environment for process operators: a review. *Virtual Reality, 23*(3), 293-311.

Sissamperi, N., & Koliopoulos, D. (2015). A didactical approach of large-scale electricity generation systems at the elementary school level. *Educational Journal of the University of Patras UNESCO Chair, 2(*2), 14-24.

Sissamperi, N., & Koliopoulos, D. (2021). How students of primary school understand large scale energy systems: The case of thermal power plant. *Journal of Technology and Science Education, 11*(1), 129-145.

Stavropoulos, V., & Koliopoulos, D. (2019). Teaching energy concepts in complex technological systems: The case of the car. *Educational Journal of the University of Patras UNESCO Chair, 6*(1), 308-314.

Stavroulia, K. E., & Lanitis, A. (2017). On the potential of using Virtual Reality for teacher education. In P. Zafiris & A. Ioannou (Eds.), *Learning and Collaboration Technologies* (pp. 173-186). Springer.

Tiberghien, A. (2004). Causalité dans l'apprentissage des sciences. *Intellectica, 38*, 69-102.