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Pre-service teachers' ideas about obtaining electricity in nuclear power stations in a role play context

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Abstract

This study examined whether participation in a role play on the socio-scientific issue of the use of nuclear power had an impact on pre-service primary teachers' ideas regarding the process of obtaining electricity in a nuclear power station. Before and after the role play, 78 pre-service primary teachers were asked to describe this process to analyze the ideas they displayed about the stages involved in it. The results showed, overall, an increased presence of more scientifically informed ideas in some of these stages following the role play, although a number of non-scientifically informed ideas persisted, for example, regarding the way in which heat is obtained or the final transformation of energy into electricity. These results support the potential value of role play for developing more scientifically informed ideas, although some modifications of the role play are recommended for further development of them.

Keywords: role play, socio-scientific issues, nuclear power stations, scientific ideas

INTRODUCTION

Role play is considered a valuable tool in the context of science education (Belova et al., 2015; Craciun, 2010). Knowledge, beliefs, opinions, values, attitudes, skills, and sensitivities may all be explored through role playing, and it is thus a good way of exposing students to a range of different viewpoints (Wijaya & Fanani, 2019). Accordingly, the ability to develop an argument, linking explanations to evidence, is an important skill when participating in a role-play activity (Simonneaux, 2008).

Given these features, role play may also be a useful way of addressing socio-scientific issues (SSIs), which by their very nature are complex open-ended problems, controversial, without a single clear-cut solution, and require evidence-based scientific reasoning in order to reach an informed opinion (Sadler, 2011; Zeidler, 2014). The use of nuclear energy possesses all the key characteristics of an SSI, has had a major impact on recent world history across a variety of domains (technology, economics, politics, the environment, and culture and society), and remains highly relevant today (Solbes & Torres, 2018). To become involved in these SSI, citizens also need to possess certain scientifically informed ideas (Namdar & Shen, 2016; Skamp et al., 2019), such as the process of nuclear fission, the effects of the radioactivity of nuclear waste, and the energy transformation during the processes that take place in a nuclear power station, among others. It is therefore an issue that needs to be addressed within science education, and hence in the training of future science teachers. Accordingly, the task for science educators is to identify the most effective ways of fostering scientific ideas among future teachers.

Although several studies have considered the use of role play in science education (e.g., Belova et al., 2015; Craciun, 2010), and to a lesser extent in teacher training (e.g., Cruz et al., 2020; España et al., 2013; Howes & Cruz, 2009), little attention has been paid to whether role-play activities might help students to acquire more scientifically informed ideas. According to Cakici and Bayir (2012, p. 1077), 'the few studies reported in the literature [have] found that role play/drama has a positive effect on children's scientific learning'. More specifically, some authors have found that role plays can help to develop science concepts and ideas among primary students (Maharaj-Sharma, 2008), while others

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Contribution to the literature

- Little attention has been paid in the literature about whether role-play activities might help students to acquire more scientifically informed ideas.
- This work makes a novel contribution to this field by analyzing the impact of role plays in the pre-service primary teachers' ideas about the process of obtaining electricity in nuclear power stations.

report a positive impact on students' perception of knowledge acquisition (Schnurr et al., 2015). It is unclear, however, whether these results are extrapolatable to pre-service teachers.

The aim of the present study is therefore to examine the extent to which role play is a useful way of helping pre-service primary teachers (hereinafter, PPTs) develop more scientifically informed ideas about SSIs, specifically in this case, the process of obtaining electricity in a nuclear power station.

THEORETICAL FRAMEWORK

Role Play and Scientific Ideas

Role play is a teaching strategy in which students play the part of different stakeholders in relation to a particular situation or issue. Because participants in a role play are required to represent a range of predefined opinions, they are confronted with opposing points of view and may, depending on the role they are assigned, have to defend a position that does not coincide with their personal beliefs. This stimulates and enriches debate and allows for exploration of a wide variety of different opinions on a given issue (Casas-Quiroga & Crujeiras-Pérez, 2020). In the experience described in this work, role play is used as a teaching strategy to practice argumentation, following the line of other studies which focus on argumentation as a means of knowledge acquisition (Iordanou & Kuhn, 2020).

In the last decades, initiatives began to promote a change in the teaching of traditional sciences by trying to replace master classes and memorials with other more innovative methodologies (Santamaría-Cárdaba, 2020). During this time, various studies have shown that role-play activities have educational benefits. In a qualitative study with an open-ended pre-/post-test carried out with 262 students between 15 and 20 years old (Agell et al., 2015) found that role plays are an effective way of shaping students' opinions, encouraging them to develop arguments in relation to contemporary problems. In addition, research also suggests that role play can improve children's understanding of scientific ideas. Maharaj-Sharma (2008), for instance, qualitatively analyzed the responses of 29 children aged 9-11 to an open-ended pre-/post-test and individual interviews after participating in a role play. The author reports how a role play helped them to develop more scientifically correct ideas. With 18 students of a similar age, 10-11, using open-ended pre-test/post-test and qualitatively analyzed, Cakici and Bayir (2012) found that a role play inspired by the history of science and portraying the lives of scientists helped children to move beyond their initially naïve conceptions of the nature of science. All of the above-mentioned works followed a very similar qualitative methodology to the one carried out in this work. From another perspective, Schnurr et al. (2015) found that role play improved students' ratings of perceived content knowledge, arguing that this supports the idea that stimulating student interest translates into increased self-reported knowledge. Quantitative studies have also found some learning benefits of role plays compared to other types of instruction (Ferreira & Faustino, 2013; Franciosi & Mehring, 2015; Soekarjo & van Oostendorp, 2015). However, de Sá Ibraim and Justi (2022) consider that role plays are restricted to situations in which there is role simulation, something that is not always present in situations focused on teaching scientific curricular content.

Results such as these suggest the necessity of new research about the use of role play as a teaching strategy that can enable students to acquire more scientifically informed ideas. A context in which role play may be particularly useful is that of SSIs, insofar as the arguments they generate are based on both scientific and everyday knowledge (de Sá Ibraim & Justi, 2016), which when expressed often produce conflicting points of view.

Pre-Service Teachers and the Issue of Nuclear Power

Although proposals can be found in the literature for addressing the SSI of nuclear energy with pre-service teachers (Fernández-Oliveras et al., 2022; Saglam & Eroglu, 2022), many of these studies have focused on describing their attitudes (Kilinc et al., 2013), values, opinions, feelings, preferred sources of information or processes of informal reasoning, and decision making (e.g. Ates & Saracoglu, 2016; Ercan et al., 2015), with scant attention being paid to their scientific ideas. Those studies which have addressed the latter have yielded contrasting results, thus highlighting the need for further research. Whereas some authors conclude that pre-service teachers have an insufficient understanding of how nuclear power stations work (Es et al., 2016), others have found that most of their participants had an adequate level of knowledge in this respect (Cansiz & Cansiz, 2015). The results of intervention studies examining the impact of instructional activities related to the SSI of nuclear power stations suggest that learning experiences of this kind can have a positive effect on students' reasoning and decision-making processes (Evren & Aycan, 2018).

Few studies have examined the use of role play for exploring issues related to nuclear energy. Crujeiras-Pérez et al. (2020) found that scientific/technological knowledge was the second most common type of knowledge used by PPTs for argumentation in the context of a role play activity on establishing a nuclear cemetery, although it was not always correct from a scientific point of view. Outside of the role play context, Ozturk and Yilmaz-Tuzun (2017) found that arguments based on scientific and/or technological questions were used by a minority of pre-service science teachers, whose reasoning was more likely to focus on the risks of the use of nuclear energy and on social and ecological aspects. These studies suggest that pre-service teachers may have an insufficient or incorrect grasp of certain scientific and technological concepts, and that this impacts their argumentation in relation to SSIs. In this respect, it is important to remember that the extent to which a person understands the various facets of an SSI, which includes scientific concepts (Sadler, 2004), may influence their informal reasoning and decision-making processes (Sadler & Zeidler, 2004).

Research Questions

A starting premise of the present study was that the use of role play may help PPTs to develop more scientifically informed ideas about an SSI, insofar as students are more likely to acquire relevant knowledge through activities that require argumentation (Simonneaux, 2001). The two specific research questions were, as follows:

1. To what extent, if at all, does a role play on the SSI of the use of nuclear energy help PPTs to develop more scientifically informed ideas about the process of obtaining electricity in a nuclear power station?
2. What non-scientifically informed ideas do PPTs hold about this process and to what extent do these persist after participating in the role play?

METHOD

This was a longitudinal idiographic study using mixed methods. Involving both pre-test and post-test data collection and both qualitative and quantitative analysis and interpretation of results (Creswell, 2014). Given that this is not an experimental research, in this work there was no control group, as in other similar works on role play and nuclear energy (Crujeiras-Pérez et al., 2020; Evren & Aycan, 2018; Freire at el., 2016).

Participants

Participants were a total of 125 PPTs (aged 21-22 years old) studying in two class groups (n=69 and n=56) enrolled in the teaching science module in year three of a four-year degree offered by the University of Malaga during the 2018-19 academic year. The majority of them had studied science for the last time as part of their compulsory secondary education (aged 14-16 years). In this respect, they were similar in profile to PPTs from other Spanish universities (Verdugo et al., 2019). Sampling was intentional, with participants being chosen on the basis of being enrolled in the aforementioned course module.

Learning Context

The use of nuclear energy has been a media topic in many countries for decades, so it is a topic with which the public is familiar (European Commission, 2009, 2022; Saad, 2022). Although this topic is not included in the Spanish primary curriculum (Ministry of Education and Vocational Training, 2022), we consider it appropriate to address SSI with PPTs, given that it has the suitable characteristics to the cognitive level of the students, in that case, undergraduate students. For all these reasons, the use of nuclear energy has been used as an SSI with PPTs (Atabey & Arslan, 2020; Crujeiras-Pérez et al., 2020; Ozturk & Yilmaz-Tuzun, 2017) and it also seems to be an appropriate topic to address with them as a context to learn how to teach an SSI through role play.

The design of the role play used in this study as a teaching strategy was informed by the results obtained in previous similar investigations (Cruz et al., 2020; España & Prieto, 2005). The role play consisted of three parts:

1. presentation of the role play to the PPTs and role assignments,
2. role preparation, and
3. staging.

The aim was to enable and encourage debate, especially as regards argumentation, and to develop PPTs' critical thinking with respect to the question of the use of nuclear energy. The inspiration for the role play was a news report regarding an agreement by the country's major electricity companies to gradually close Spain's nuclear power stations over the period 2025-2035 (RTVE, 2019). With this as our starting point, we designed the staging of the role play in the form of a television debate involving a total of ten stakeholders that PPTs would represent and a program presenter and production team. Class tutors were present solely as silent observers.

The two aforementioned PPTs classes were first divided into two groups (with 30 PPTs each one of them), thus allowing for four role plays to be conducted under identical conditions. This grouping into four

Figure 1. Photograph taken during the staging of one of the role plays

groups was to ensure that all the PPTs could actively participate in the experience, given the high number of them by class. Therefore, for each role play, 10 teams of three-four PPTs were formed to represent each role, with each team being assigned to one of the ten roles in the televised debate. Teams nominated one member to act as spokesperson, while the remainder acted as advisors. Spokespersons and advisors were assigned a number of different tasks during the role play, and in this way, we ensured that all PPTs were active participants in the staging.

In the photograph shown in **Figure 1**, the PPTs seated in the front rows are team spokespersons, while those seated behind them are their respective advisors. The two PPTs at the far end (facing the camera) are in the role of program presenter and producer.

In a first session, prior to the role play staging itself, all PPTs completed a pre-test (see data collection and analysis section below for details of the question). This session was also used to introduce them to the idea of role play as a teaching strategy, to provide them with information about the activity they would be performing (i.e., the context, roles, and rules) and to assign them to teams (España & Prieto, 2005). Finally, each team was given a role card containing a brief profile of the role they were going to represent, along with the instruction to locate information and arguments in support of the perspective they would be defending. The use of role cards of this kind places more demands on students as they are not given detailed guidance, but in this way, they are able to develop their own arguments based on the information they retrieve (Belova et al., 2015). Furthermore, the descriptions on these cards were in line with three possible positions:

1. using nuclear energy indefinitely,
2. nuclear phase-out in the short term, or
3. nuclear phase-out in the medium term.

In addition to the role cards, each team was given the worksheets they would be required to complete during the staging of the role play (**Table 1** and **Table 2**). Prior to the role play, PPTs had received no formal instruction from tutors on the topic of the use of nuclear energy, although some key scientific concepts (e.g., methods of uranium reprocessing) were referred to on the role cards. The PPTs teams were given one week, following this initial session, to prepare their arguments for the staging of the role play.

The staging of the role play took place during a second session and was divided into three parts. In the first part, the spokesperson of each team was given three minutes in which to present their initial arguments, which they had to have listed on the first worksheet prior to attending the role play session (see first column in **Table 1**).

This worksheet also included columns for noting down the counterarguments put forward by other teams, as well as refutations of these (see second and third columns of **Table 1**) that would be used in the second part of the role play.

During this part of the staging of the role play, the task for team advisors was to note down, on a second worksheet, the strengths and weaknesses of the arguments put forward by the other roles (see example in **Table 2**).

Once each of the 10 teams had presented its arguments, there was a five-minute break (simulating an advertising break in a televised debate) during which the advisors of each team discussed with the spokesperson the strong and weak arguments put forward by the other teams, thus allowing refutations to be developed; the counterarguments put forward by other teams, as well as the refutations of these, had at this point to be added to the first worksheet in preparation for the second part of the role play.

Table 1. Fragment of a worksheet completed prior to the staging of the role play (first column) & during the second part of the staging (second & third columns), in this case corresponding to the team of PPTs in the role of a member of the public

Prior to the staging (prepared as a homework task)	For the second part of the staging	
Initial argument	Counterargument by other roles	Refutation
The general public believe that nuclear power stations are harmful because they increase pollution (Source: http://archivo-es.greenpeace.org/espana/Global/espana/report/cambio_climatico/por-que-digo-no-a-la-energ-a.pdf).	Nuclear energy does not create pollution. Although nuclear waste may be toxic, it can be safely stored.	Nuclear waste is extremely harmful to the environment & society. Accidents or malfunctioning of storage sites would have a devastating impact on people living nearby.
Nuclear terrorism is now a threat. People are aware of the devastating power of nuclear energy, & material could be stolen to be used as a weapon (Source: https://elpais.com/diario/1978/09/09/sociedad/274140017_850215.html).	Although nuclear terrorism is a potential threat, production sites have security guards & technology to avoid theft of material.	The threat of the misuse of nuclear energy does not only relate to those who might engage in nuclear terrorism. It is often our own governments who use it as a weapon of war.
Any nuclear accident could have a devastating impact on society (Source: https://www.rtve.es/noticias/20090702/51-razones-contra-energia-nuclear/283255.shtml).	The design of newer nuclear power stations means they are safer & less contaminating.	New designs may still fail, whereas there are no risks associated with renewable energy, it is safe & efficient.

Table 2. Example of the worksheet completed during the first part of the staging by the team of PPTs in the role of a member of the public (In square brackets, []: our own annotations added for the purposes of clarity)

Roles	Weak/strong arguments
Ecologist	Weak arguments: A nuclear cemetery produces a certain amount of waste (without supporting evidence). Strong arguments: They are a source of contamination, especially due to uranium and radioactivity.
Renewable energy scientist	Weak arguments: Reduction in number of jobs. Strong arguments: Effect on climate change.
Member of the public	[No comments].
Solar energy entrepreneur	Weak arguments: [No comments]. Strong arguments: [No comments].
Politician from the opposition	Weak arguments: Contamination not as much a problem as people believe. Strong arguments: Provide a lot of jobs.
Government politician	Weak arguments: There are tubes that release less sulfur, uranium, and all this kind of waste. Strong arguments: [They can be] complemented by other kinds of power station.
Manager of a nuclear cemetery	Weak arguments: Fewer illnesses, energy production is cheaper. Strong arguments: Production is possible without influencing the [greenhouse] effect, strict control over production.
Nuclear scientist	Weak arguments: [No comments]. Strong arguments: [No comments].
Manager of a nuclear power station	Weak arguments: [No comments]. Strong arguments: [No comments].
Worker of a nuclear power station	Weak arguments: Provide a lot of jobs. Strong arguments: There are medical check-ups and strict safety controls.

Following the five-minute break, in the second part of the staging, the various spokespersons debated with one another, attempting to counter each other's arguments in support of their own position. The task for advisors during this part of the role play was to support their team spokesperson by continuing to propose refutations of the arguments put forward by other teams.

During the debate, the program presenter and production team had to use an open-access tool of their choice (the most commonly used were Socrative and Mentimeter[1]) so as to display on a screen the comments that participants wished to make, thus simulating audience opinions. At the end of the debate, the program presenter gave a summing up, highlighting key themes and opinions that had emerged during the discussion and, if they considered it necessary, asking participants to vote in favor or against the proposed closing of nuclear power stations. At the end of the role play, PPTs completed a post-test.

[1] Applications are available at https://socrative.com/ and https://www.mentimeter.com/

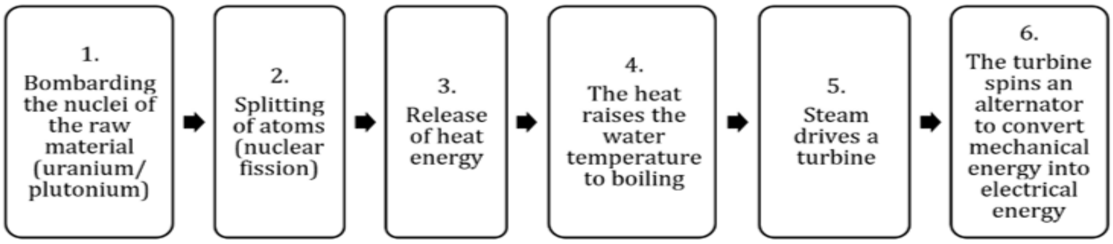

Figure 2. Process diagram showing how electrical energy is obtained in a nuclear power station

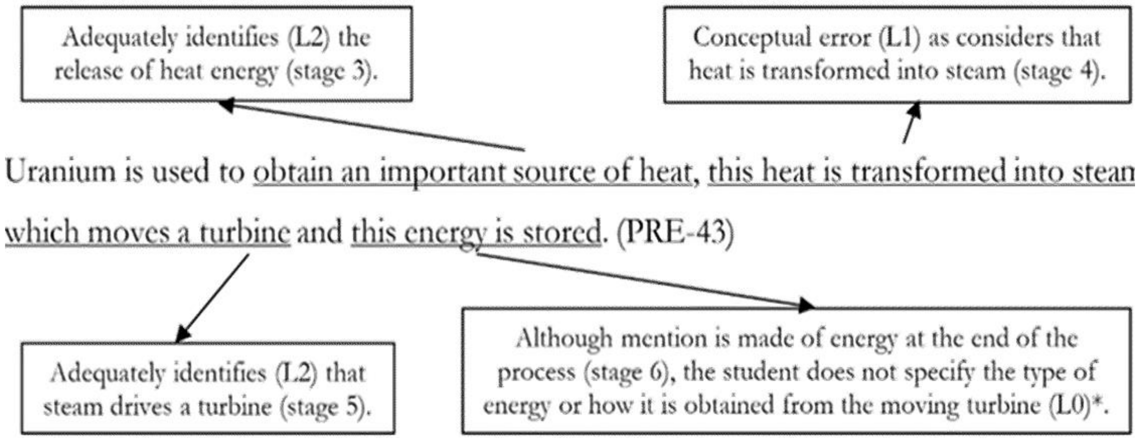

Figure 3. Example of the process of analyzing and categorizing a PPT's answer (*Example of part of an answer classified as level 0; in this case we considered that the PPT did not describe any aspect of stage 6 of the process)

Data Collection and Analysis

Data were collected by asking PPTs the same open question at two time points: pre- and post-test. The pre-test was filled in by the PPTs before providing them any information. It was the first task, before explaining the rules and the roles of the role play. The post-test was filled in immediately after their participation in the role play. The question was as follows: Describe, from start to finish, the process of obtaining electricity in a nuclear power station. We consider that scientifically informed ideas about this process are a basic aspect for citizens to get involved and make informed decisions about the issue raised in the role plays, since they are at the basis of the concerns raised by the public about the use of nuclear power stations, such as safety, environmental consequences, or health effects (European Commission, 2009).

The process diagram shown in **Figure 2** used to analyze their answers was based on information provided by two government agencies in Spain, the Ministry for the Ecological Transition and the Demographic Challenge (2019) and the Nuclear Safety Council (2019).

PPTs' answers to the pre-/post-test question were analyzed in terms of their structure, that is, the extent to which they reflected the process stages shown in **Figure 2**, and also the level of scientific ideas they implied. More specifically, and with the aim of highlighting non-scientifically informed ideas in PPTs' answers, we analyzed how accurate they were in their use of scientific language, looking for conceptual errors and inaccuracies in their description of the processes involved in obtaining electricity in a nuclear power station. With regard to stages in this process, PPTs' answers were rated according to the following three levels:

1. **Level 0 (L0):** does not mention a given stage. PPTs who left their answer paper blank and those who said they did not know how nuclear energy was produced were also assigned this level.
2. **Level 1 (L1):** presence of non-scientifically informed ideas due to inaccuracies and/or conceptual errors.
3. **Level 2 (L2):** is adequate from a scientific point of view, suggesting that the PPTs understands the basic concepts included in a certain stage.

By way of an example, **Figure 3** shows the analysis of a PPT's answer based on the process diagram and the above three levels. It can be seen in this example that an answer could contain references to various stages of the process.

Hereinafter, examples of PPTs' answers are labelled as either PRE or POST (depending on whether they refer to the pre- or post-test), followed by the number assigned to the PPT in the anonymized data collection. Where necessary, any spelling mistakes in PPTs' answers have been corrected, but their content has not been altered in any way.

PPTs who did not answer the pre-test and/or post-test (n=51) were eliminated from the data set and the subsequent analysis. Some PPTs could not attend the staging of the role play and did not answer the post-test, although they had answered the pre-test. In other cases, the pre-service teachers could not attend the session in which the pre-test was presented, and they were not able to fill in it, so they were eliminated too. Therefore, these questionnaires had to be eliminated.

The pre- and post-test answers given by the remaining 74 PPTs were first examined and categorized by two of the authors working independently, following which we calculated the degree of inter-rater agreement. Any disagreements were resolved through discussion and consensus among all members of the research team. The analysis involved two stages: first, we identified the process stages (from 1 to 6) that were implied in PPT' answers and the level assigned to the corresponding part of their answer (L0, L1, or L2), and second, we examined pre- versus post-test changes in the number of stages referred to in their answers (L1 and L2).

Statistical Analysis

To determine the reliability of the final categorization of answers, we calculated, for each aspect analyzed, the percentage agreement and the value of weighted Cohen's kappa, which ranges from 0 to 1, where 1 indicates maximum agreement. Specifically, we used weighted kappa with Cicchetti weights (Fleiss, 1981), which assign different weighting values depending on the degree of disagreement between raters.

The seven aspects analyzed (presence of stages 1, 2, 3, 4, 5, and 6 and number of stages) yielded agreement above 70%. Regarding weighted kappa, five of the aspects (presence of stages 1, 2, 3, 4, and 6) yielded values between .61 and .80, a range considered by Landis and Koch (1997) as reflecting substantial agreement, while the remaining two aspects (stage 5 and number of stages) had kappa values above .81, which the same authors interpret as indicating almost perfect agreement.

The final categorization of answers was subjected to both descriptive and inferential analysis. In the former case, we recorded absolute frequencies for each of the six stages according to the three levels of categorization. To examine whether there were significant differences between pre-test and post-test answers, we first applied a test of normality, which showed that the data were not normally distributed. Consequently, and given that we were dealing with ordinal qualitative variables, we used the non-parametric Wilcoxon signed-rank test for paired data (pre- and post-test). We also calculated the effect size (r) for the magnitude of differences, which were interpreted as follows: small (.10≤r<.30), medium (.30≤r<.50) or large (r≥.50) (Coolican, 2009).

RESULTS

Firstly, the overall results obtained are shown and then the non-scientifically informed ideas found in each of the stages are detailed, ending with the analysis of the number of stages that the PPTs identify in their answers to describe the process. **Table 3** shows the answers categorized at each level according to stage of process.

Table 3. Absolute frequencies for description of stages in PPTs' answers, classified according to three levels at pre- & post-test

Level	Stage 1		Stage 2		Stage 3		Stage 4		Stage 5		Stage 6	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
L0	74	71	53	36	66	50	65	55	65	48	35	31
L1	0	1	16	14	1	2	7	8	2	8	31	22
L2	0	2	5	24	7	22	2	11	7	18	8	21
Total	74											

Table 4. Results of Wilcoxon signed-rank test for each stage (post- versus pre-test)

Stage	Negative ranks	Positive ranks	Wilcoxon signed-rank test			
			Ties	Z	p-value	r
1	0	2	72	-	ns	-
2	0	19	55	-4.359	.000	.385
3	4	19	51	-3.128	.002	.276
4	2	11	61	-2.496	.013	.221
5	3	14	57	-2.668	.008	.236
6	2	15	57	-3.153	.002	.279

Note. Z: Test statistic; r: Effect size; ns: Not significant (for significance level=.05)

The number of answers with content categorized as L2 increased for all stages between pre- and post-test. The stages most commonly referred to in a scientifically sound way were numbers 2 and 3, followed by stages 6, 5, and 4. Descriptions of stage 1 were the least frequent at both pre- and post-test. It can be seen that conceptual errors and inaccurate ideas (L1) persisted after the role play in relation to stages 2 and 6. In order to determine whether there were significant differences between pre-test and post-test, we applied the Wilcoxon signed-rank test. For this analysis we merged levels 0 and 1, indicating no mention or non-scientifically informed ideas about a given stage, and compared this with the number of answers with content reflecting level 2 (scientifically informed ideas of a given stage).

Table 4 shows the results of the Wilcoxon signed-rank test for each stage. For all stages, there was a higher number of positive than negative ranks, indicating a shift from L0 or L1 to L2 between pre- and post-test. It can be seen in **Table 4** that, with the exception of stage 1, the difference was significant, indicating that PPTs' answers were significantly more likely to contain content categorized as L2 at post-test. The effect size for these differences was small for all stages except stage 2, where it was medium.

We will now discuss the results obtained in relation to each of the six stages in the process of obtaining electricity in nuclear power stations, comparing their presence in the pre- and the post-test and identifying the misconceptions and inaccuracies present in the PPTs' answers to each one of them.

Stage 1

This stage (bombarding nuclei of uranium/plutonium) was the least present (L0) in the PPTs responses in both the pre- and post-test. Only three PPTs referred to it at post-test, one of them as a non-scientifically informed idea (L1) and two scientifically informed ideas (L2), suggesting that the role play did not improve their scientific ideas in this respect. As regards inaccurate ideas, one PPT referred at post-test to particles colliding, without specifying any details: '[...] and then the particles of these materials collide with one another [...]' (POST-22).

Stage 2

Stage 2 (splitting of atoms, nuclear fission) was the second most frequently mentioned at pre-test and post-test, although some of the descriptions were at L1. There is an increase in the number of PPTs who did not mention the stage (L0) and in the percentage of answers at L2.

Below we list the non-scientifically informed ideas that were expressed in relation to this stage. In each case, we indicate the number of answers that contained the idea in question at pre- and post-test (shown in brackets and separated by a slash, for example, 11/5).

1. The term 'fission' is mentioned without explaining what it implies, or reference is made to the process that the raw material undergoes using very general terms such as 'transformation', 'treatment' or 'decomposition' (11/5). Example: '[...] through fission, we modify nuclear elements [...]' (POST-7).
2. The process that takes place in a nuclear power station is described as nuclear fusion, or as both fission and fusion (1/6). Example: '[...] processes involving fusion to obtain energy' (POST-10).
3. The raw material is subjected to chemical processes or reactions (2/1). Example: 'They carry out chemical processes until it is turned into energy' (POST-9).
4. The process of obtaining heat in a nuclear power station is the result of combustion (2/1). Example: 'The fossil fuel is burned' (PRE-50).
5. The nuclear reactor core itself undergoes nuclear fusion, rather than it being where the fission reaction takes place (0/1): 'With the radioactive elements, the water is heated, and this produces the fusion of the core' (POST-8).

Stage 3

In this stage (release of heat energy), there is a considerable increase in the number of answers in which it is mentioned at L2, seven at pre-test and 22 at post-test. The following non-scientifically informed ideas were observed:

1. Reference is made to obtaining energy, without specifying its type (0/2). Example: 'First, energy is obtained, and then steam is produced which drives turbines, and it is these that produce mechanical energy that drives a generator that produces the electricity' (POST-15).
2. Confuses heat, as a process of energy transfer, with a kind of energy (1/0): 'Then, the energy that is released is transformed into heat' (PRE-50). In this example, the release of energy is distinguished from heat, as if the two were unrelated; the PPT fails to recognize heat as a process of thermal energy transfer.

Stage 4

Stage 4 (heat raises the water temperature to boiling) was mentioned (L1 plus L2) in nine answers at pre-test and nineteen at post-test. There is an increase in the number of PPTs who mentioned this stage at L2, 2 at the pre-test and 11 at the post-test. The non-scientifically informed ideas we observed in these answers were:

1. Steam is a product of nuclear fission (2/4). Example: 'Fission takes place, and this releases energy and steam […]' (POST-1).
2. Inaccurate description of the stage (3/3). Example: 'First, energy is obtained, and then steam is produced that drives the turbines […]' (POST-15).
3. Heat is turned into steam, as if the process involved transformation of one substance into another (2/1). Example: 'Uranium is used to obtain an important source of heat, and this heat is transformed into steam […]' (PRE-43).

Stage 5

In stage 5 (steam drives a turbine), there was an increase in the number of answers that mentioned it, nine at pre-test and 26 at post-test and in the number of answers at both L1 and L2. The non-scientifically informed ideas expressed were as follows:

1. The turbine is omitted, stating instead that it is steam that moves the alternators, as well as other ideas that do not reflect how turbines work (1/5). Example: '[…] and this activates a turbine that generates steam [...]' (POST-70).
2. Heat or fission is stated as being responsible for driving the turbine (1/3). Example: '[…] and this can be obtained through nuclear fission, which moves a turbine […]' (POST-45).

Stage 6

Stage 6 (the turbine spins an alternator to convert mechanical energy into electrical energy) was the most commonly described (at L1 or L2) at both pre-test (39 answers) and post-test (43 answers). There was a

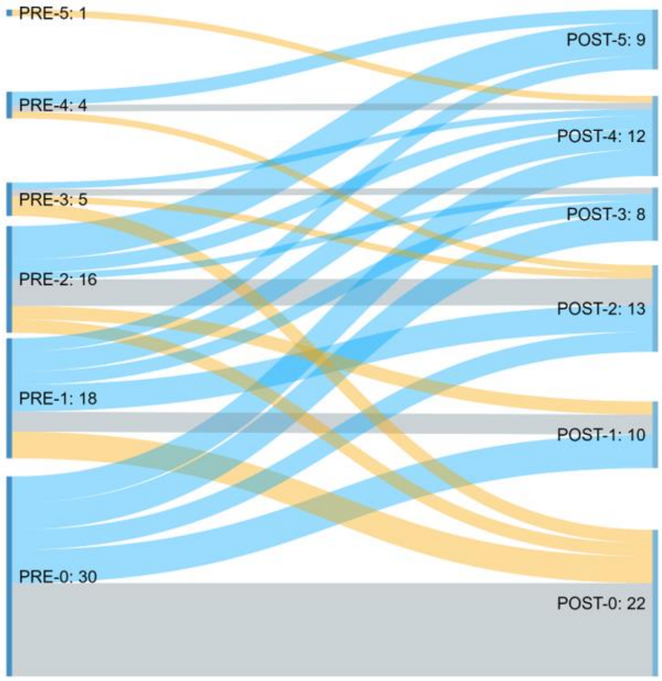

Figure 4. Sankey diagram showing change between pre-test and post-test in the number of process stages referred to by PPTs in their answers

Figure note: Diagram was created using SankeyMATIC.

decrease in the number of answers at L1 and an increase at L2.

The non-scientifically informed ideas expressed in this stage were:

1. Electrical energy is the final product but is obtained directly from earlier stages of the process, such as fission, heat or steam, or the turbine but without an alternator (11/14). Example: 'A fission reaction splits two or more atoms, producing electrical energy' (POST-26).
2. The use of terms such as 'create' or 'produce' to refer to the final obtaining of energy (16/7). Example: '[…] use of machines that will produce the energy [...]' (PRE-10).
3. The final product of the process is nuclear energy, not electrical energy (2/1). Example: '[…] steam drives turbines that help to produce nuclear energy […]' (PRE-27).
4. Heat is mentioned, but not the fact that electrical energy is obtained, which in our view suggests that the PPT considers thermal energy to be what results from the process (2/0). Example: 'A nuclear reaction takes place and produces heat, which generates waste products that are not eliminated' (PRE-26).

Number of Stages Identified in PPTs' Description of the Process

We also analyzed the number of stages that were present in PPTs' answers at both pre- and post-test and the changes that took place between them (**Figure 4**).

The labels in the Sankey diagram (**Figure 4**) indicate whether the data refer to pre-test (PRE) or post-test (POST), followed by the number of stages identified and the number of PPTs whose answer referred to this number of stages. For example, the label PRE-2: 16 indicates that at pre-test a total of 16 PPTs made reference to 2 stages in their answer. The width of the flow lines is proportional to the number of PPTs they represent. Ascending flows (i.e., higher number of stages referred to at post-test compared with pre-test) are shown in blue, while descending flows (i.e., lower number at post-test) are in yellow; the grey lines indicate no pre- vs. post-test change in the number of stages referred to. The vertical side bars (nodes) indicate the number of PPTs who described a given number of stages in their answer (from 0 to 5, as no PPT referred to all six stages of the process), at pre-test (PRE) on the left and post-test (POST) on the right. It can be seen that there are more ascending flow lines (13) than descending ones (7), and also that the former are generally wider than the latter, indicating a net increase in the number of PPTs who describe more process stages at post-test descending lines reflect a decrease of three in the number of stages described (e.g. from 3 at pre-test to 0 at post-test), whereas the steepest ascending lines show an increase of four (from 0 to 4, or 1 to 5 stages). The median of the number of stages described at the pre-test was 1 and 2 at the post-test.

Application of the Wilcoxon signed-rank test to the aspect 'number of stages described in an answer' showed that PPTs described a significantly higher number of process stages at post-test ($Z=-4.029$; $p=.000$), with a medium effect size ($r=.356$).

DISCUSSION

Overall, the results show improvements in PPTs' scientifically informed ideas about the stages of the process of obtaining electricity in a nuclear power station. However, these improvements are not equal in the quality of descriptions of the different stages of the process. The quality of description of all the different process stages improved following the role play, with the sole exception of the first stage (bombarding the nuclei of the raw material). It should be noted, however, that the effect size of significant differences between pre-test and post-test was small for all stages except for stage two (splitting of atoms-nuclear fission), where it was medium. Similarly, the effect size was medium for the number of stages included by the PPTs in their answers.

In addition to these findings, our analysis also showed that PPTs held a number of non-scientifically informed ideas, due to inaccuracies and/or conceptual errors, about the process of obtaining electricity in a nuclear power station, some of which persisted after the role play. These non-scientifically informed ideas were generally related to energy and its transformation

(Pontes, 2000; Solbes, 2007), and in particular to the physical reactions (bombardment of nuclei and fission) that take place in a nuclear power station (Jho et al., 2014). In line with other studies (Domínguez et al., 1998; Pontes, 2000; Solbes & Tarín, 1998), we also observed that some PPTs, when referring to stage 3 of the process (release of heat energy), thought that heat was a type of energy rather than the result of energy transfer. On this issue, Solbes (2007) argues that students struggle to understand heat as a mechanism of energy transfer because they have not grasped the concept of energy loss. Another closely related non-scientifically informed idea was expressed in relation to stage 6 of the process (the turbine spins an alternator to convert mechanical energy into electrical energy), with some PPTs believing that heat was the final product. This suggests that these PPTs are understanding heat as thermal energy and, erroneously, as a product that can be stored (Solomon, 1985) and distributed, in other words, as a state function (Domínguez et al., 1998). Also, in relation to stage 6 of the process, some PPTs made a common conceptual error about energy, confusing its forms with its sources (Solomon, 1985).

With regard to the moment or moments at which these non-scientifically informed ideas appear, two situations deserve to be highlighted. For this purpose, only those with a certain prevalence have been considered, which we have delimited by their presence in more than five responses, in pretest, in posttest or in both.

1. Those that were hardly mentioned in the pre-test and appear in the post-test. This group includes the use of the term fusion or fission and fusion together (see stage 2, point 2) and the omission of the turbines or incorrect ideas about how turbines works (5.1). In these cases, it is possible to suppose that these non-scientifically informed ideas were used during the staging and taken up in the post-test by some PPTs who had not included them in the pre-test. The use of fusion instead of fission seems to be a clear example of terminological confusion since, at the same time, there is also an improvement in the precise use of the term fission (2.1).
2. Those mentioned in both the pre-test and post-test. In this situation we encounter the conceptual error that steam is a direct product of nuclear fission (4.1), which highlights the lack of understanding of this stage, which is also evident in the inaccurate descriptions of this stage (4.2).

CONCLUSIONS AND EDUCATIONAL IMPLICATIONS

In this study we sought to explore the ideas held by PPTs about the process of obtaining electricity in a nuclear power station, both before and after participation in a role play related to the SSI of the use of nuclear energy. Regarding our first research question (To what extent, if at all, does a role play on the SSI of the use of nuclear energy help PPTs to develop more scientifically informed ideas about the process of obtaining electricity in a nuclear power station?), the analysis suggests, overall, that the role play led to significant improvements in PPTs' scientifically informed ideas about the different stages of the process. This lends support to the claim that role play can be an effective way of developing students' understanding of scientific concepts and ideas (Maharaj-Sharma, 2008) that underpins SSIs (Mikeska & Howell, 2020), not only for raising students' awareness and shaping their attitudes (Bossér & Lindahl, 2020), as is widely recognized in the literature. However, these improvements are moderate, considering that they are restricted to certain aspects of knowledge assessed and the persistence of misconceptions after the experience.

With respect to our second research question (What non-scientifically informed ideas do PPTs hold about this process and to what extent do these persist after participating in the role play?), the results indicate that the non-scientifically informed ideas held by our PPTs with regard to the process of obtaining electricity in a nuclear power station are consistent with those described by other authors in students of different educational stages, including undergraduates. As in previous studies (Iscan & Seyhan, 2021; Jho et al., 2014; Pontes, 2000; Solbes, 2007), the misconceptions we encountered were related especially to the general concept of energy. Importantly, although we observed a significant shift towards more scientifically informed ideas following the role play, a number of erroneous ideas remained at post-test, and in some cases were expressed by PPTs who had not done so prior to the role play. In addition, it should be noted that the participating students have not shown to be able to give a detailed description of nuclear processes, but only a superficial one. With regard to these processes, many studies with high school and university students have shown that they have conceptual errors in nuclear chemistry and physics (Kohnle et al., 2011; Nakiboglu & Tekin, 2006) that would be expected to be found in the participating PPTs.

What our analysis reveals, therefore, is that the improvement in PPTs' scientific ideas was limited to certain aspects of the process of obtaining electricity in a nuclear power station, and many of them continued to have a poor grasp of the physical concepts involved in the process and/or to show inaccuracies in their use of scientific vocabulary (Domínguez et al., 1998; Pontes, 2000; Solbes & Tarín, 1998). This is illustrated by the fact that hardly any of the PPTs made reference to scientific concepts such as neutrons or the bombardment of nuclei, which are necessary for explaining the process of nuclear fission. These results show that role plays require a great deal of specific knowledge (Belova et al., 2015) and PPTs are not expected to acquire it autonomously during the development of the role play. Therefore, as Brown (2018) suggests, this seems to indicate that misconceptions about radiation and nuclear energy should be explicitly addressed in educational programs.

The nature of the study carried out has made it possible to identify changes in the PPTs' ideas about the process of obtaining electricity in a nuclear power station, but we cannot venture the reasons for these changes, which is an important aspect in order to identify and specify lines of improvement in the educational use of this role play. To this end, and as a projection of this research, it would be interesting to analyze the content of the role plays from the perspective of scientific knowledge, which scientific ideas, and when, have been used by the PPTs. On the other hand, we also think it is important to know the possible influence of the different roles played in the role play on the changes in the PPTs' ideas.

However, considering the results and conclusions obtained in this study, we believe that the role play used here could be modified according to the implications of this study to foster among PPTs a better understanding of the scientific ideas that underpins the process of obtaining electricity in nuclear power stations. The goal of these modifications would be to help them acquire key aspects of scientific ideas that did not emerge when working independently (note that PPTs were not given specific guidance or instruction regarding the scientific concepts of relevance to the role play). This could be approached in various ways. One would be to provide them with materials or sources of scientific information they could use when preparing their roles. For example, the role cards could include more detailed information about the role in question and offer tips about how to structure their inquiry, although we acknowledge that this could shape students' opinions to some extent (Belova et al., 2015). Another option would be to provide them with access to external experts (e.g., physicists or chemists) whom they could consult, either in person or online, during the process of preparing for the role play. A further issue to consider concerns the role of class tutors in the argumentation process (Evagorou & Dillon, 2011). In the role play used here, tutors were present solely as silent observers, and it would therefore be interesting to explore the impact of their guiding the debate to some extent, proposing certain topics or introducing key concepts. For example, they might suggest questions for student teams to ask during the debate so as to facilitate the emergence of key scientific ideas.

The fact that, even after the role play, our PPTs demonstrated a limited understanding of the physical concepts involved in electricity production in nuclear power stations highlights the importance of the choice of pedagogical strategy. Or to put it another way, those responsible for training future teachers of science and for helping them develop their scientific ideas about topics such as the use of nuclear energy need not only to understand the physics themselves but also to be aware of the difficulties their students may have in taking on board these concepts and ideas (Siersma et al., 2021).

To conclude, we believe that the role play described in this study could make a positive contribution to the scientific literacy of PPTs, fostering knowledge, attitudes and values related to the SSI of the use of nuclear energy and helping to develop their argumentation skills. The relationship between scientific ideas and argumentation skills is an issue that merits further investigation, insofar as both, in our view, are relevant to the decision-making processes with which citizens will have to engage over coming decades in order to address local and global problems associated with climate change and the energy transition. Obviously, teachers will also have to tackle these same issues in the classroom.

Finally, future studies should also aim to address a question posed by Maharaj-Sharma (2008), namely, how to encourage or motivate science teachers to use role-play strategies in their science teaching. In our view, incorporating role play into the training of pre-service teachers, as we have done here, can help to achieve this goal by providing them with an early opportunity to experience the benefits of such an approach.

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