Evaluando la capacidad de argumentación de maestros en formación inicial. Estudio de caso del proceso de disolución química

Assessing the argumentation ability of pre-service teachers. Case study concerning the chemical dissolution process

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RESUMEN.

La capacidad de argumentación científica de maestros/as en formación inicial (PST) en las primeras etapas de la educación es esencial, ya que proporcionarán a sus estudiantes la base inicial del conocimiento científico. Un total de 133 maestros/as de infantil (PSEC) y primaria (PSP) en formación inicial realizaron una actividad de argumentación sobre cómo tiene lugar el proceso de disolución. El diseño de esta actividad es un claro ejemplo de los diferentes niveles de complejidad de la capacidad de argumentación en ciencia. Los resultados muestran que los PSTs consolidan los niveles de identificación de pruebas y construcción de justificaciones en sus argumentos. Sin embargo, se encontró un menor desempeño en las capacidades de proporcionar una contra-crítica y construir contraargumentos. La prueba U de Mann-Whitney no mostró diferencias significativas entre los grupos en los niveles más altos de complejidad. Por el contrario, se encontraron diferencias estadísticamente significativas para la identificación de pruebas a favor de los PSPs.

PALABRAS CLAVE.

Disolución química, Argumentación, Maestros/as de infantil en formación inicial, Maestros/as de primaria en formación inicial.

ABSTRACT.

The scientific argumentation ability of pre-service teachers (PSTs) in the early stages of education is essential as they will provide students with their initial grounding in the scientific knowledge. A total of 133 pre-service Early Childhood (PSEC) and Primary (PSP) School teachers undertook an argumentation activity concerning how the dissolution process takes place. The design of this activity is as a clear example of the different levels of complexity of the argumentation ability in science. The results show that PSTs consolidated the categories identification of evidence and construction of warrant. However, the abilities to provide a counter-critique and construct a comparative argument are still not consolidated. The Mann-Whitney U test did not show any significant differences between groups with high levels of difficulty. In contrast, we found statistically significant differences for the identification of evidence in favour of PSPs.

KEY WORDS.
Chemical dissolution, Argumentation, Pre-service Early Childhood School Teachers, Pre-service Primary School Teachers.

1. Introduction.

Educational research in chemistry teaching is essential in order to develop, amongst other aspects, strategies that allow promotion of the skills and attitudes required to achieve critical and reflective citizens. Of these strategies, argumentation is a skill that has aroused considerable interest in recent years because it implies the ability to evaluate scientific statements based on evidence (Driver, Newton, and Osborne 2000). Also, the ability to “engage in argument from evidence” is one of the eight practices identified in the Next Generation Science Standards as well as an emerging focus of undergraduate chemistry curricula (Walker and Wolf 2017). Argumentation is defined as the means to recognise conclusions and statements which must be evidence-based and justified using the prior knowledge, namely backing in terms of Toulmin model (Jiménez-Aleixandre and Puig 2010; Toulmin 1958).

Furthermore, argumentation allows us to work on scientific competences such as the identification of chemical questions, the explanation or prediction of chemical phenomena by applying chemical aspects, or the use of evidence to elaborate and communicate conclusions and identify the reasoning that sustains them (Cigdemoglu, Arslan, and Cam 2017). This scientific practice develops this argumentation ability, and the metacognitive processes involves, such as Juntunen and Aksela (2014). As such, it is becoming a relevant scientific practice in the chemical classroom in various specific pedagogical approaches, such as Argument-Driven Inquiry (ADI) (Walker, Sampson, and Zimmerman 2011), Claim, Evidence, Reasoning, and Rebuttal (CER) (Zembal-Saul, McNeill, and Hershberger 2013), or the Science Writing Heuristic (SWH) (Burke, Greenbowe, and Hand 2006).

One of the schemes most widely used in science education to work on argumentation in class is the well-known Toulmin model (Toulmin 1958). It includes the following elements of an argument: a) the conclusion as part of the claims, including the transmitted idea ; b) the evidence to support this claim; c) the warrant based on prior knowledge or backing to relate this evidence to the conclusion; and d) refutation as possible arguments against the initial conclusion, which may result in contradictory ideas. This scheme can be simplified into three essential elements, namely, conclusion, evidence, and warrant (Jiménez-Aleixandre 2010). This simplification is adequate and simple to use when initiating teachers in argumentation.

Cullen (2015) has attempted to use a learning progression to improve the learning of chemistry in a coherent manner. Other studies also focus on an enhancement of the argumentation ability taking into account, amongst others, the level of complexity in the provision of evidence (Bravo and Jiménez-Aleixandre 2018) or the ability to provide a scientific explanation (Berland and McNeill 2010).

According to Osborne et al. (2016), the consideration of the competence of argumentation as a learning progression consists of two dimensions, namely construction of the argument and critique. Within each dimension, Osborne et al. (2016) established a series of difficulty levels depending on the elements used to construct or critique the argument. In the first levels, it is proposed to construct and identify the essential elements of an argument (evidence, warrant and conclusion), for the part of construction and criticism, respectively. The following levels allow students to participate in criticism and counter-argumentation. They start with the comparison of a single argument, up to incorporating two arguments where the student has to criticise both parts and construct a third more complete arguments.

Despite the existence of these different pedagogical approaches, many students still have difficulty in writing chemically, although the construction of tentative arguments and argumentation sessions seems to help them to revise written arguments and presentations (Çetin and Eymur 2017). Likewise, Stowe and Cooper (Stowe and Cooper 2017) highlighted the importance of teaching students how to argue theoretical concepts or chemical models, since the majority of students are unable to use these concepts to support the rhetoric used in scientific and engineering practices, as defined in the K12 framework (National Research Council 2012).

Scientific argumentation remains a difficult practice for students to engage in as well as for both in-service and pre-service science teachers (PSTs) to teach (Walker and Wolf 2017). As such, it requires an effort to create activities designed to develop argumentation abilities, especially in a scientific context such as chemistry, in PSTs (Aydeniz and Dogan 2016). It is especially important for PSTs in the early stages of education (early childhood and primary) as they will be the ones to train their students in the most basic concepts of chemistry. An example of one of them is how salt disappears when we add it to a glass of water and stir it. In this case, the teacher could ask a series of simple questions for the students, thus starting the development of their argumentation ability from that early age. As such, PSTs must have appropriate training in chemical argumentation.

The dissolution process and other related concepts, such as solubility, dissolution or diffusion, are often difficult for PSTs to understand as a result of misconceptions and incomplete models (Akgün 2009; Çalik and Ayas 2005) when they had a weak background. In some studies, scientific argumentation activities use different dissolution topics as contexts (Cetin 2014; Ozdem et al. 2013), and in that sense, Toulmin (1958) considered backing to be the understanding required to give a well-argued response to these activities, thus promoting a better understanding of this chemical process.

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2. Research question.

This research forms part of a broader study aimed at developing and promoting an argumentation ability and critical thinking skills in PSTs.

This work raises the main research questions:

RQ1: What are the prior level and differences in the argumentation ability by pre-service Early Childhood Education (PSEC) and Primary Education (PSP) teachers at the University of Malaga (Malaga, Spain) when undertaking an activity related to the dissolution process?

The activity about the dissolution process used in this study was proposed by Osborne et al. (2016) and forms part of an initial study to determine the starting level of argumentation of these PSTs. This activity has been chosen since it has previously been validated by those authors with 803 American students (8th and 10th graders), and from our point of view, it is important to help the chemistry education moving forward to repeat studies in different settings with different populations. So, in this paper we would also like to compare the results of Osborne et al. (2016) in secondary education with PSTs. For this purpose, this work raises the following research question:

RQ2: Do these levels of argumentation achieved by PSTs differ from those shown by other studies (Osborne et al. 2016) for grade 10 students?

Thus is suggesting its application in a PST context in this paper.

3. Method.

A total of 133 PSTs, precisely 77 PSPs and 56 PSECs who studied a science teaching course in the third year of their corresponding degree at the University of Malaga (Malaga, Spain) during the academic year 2017-18, participated in this study. Of these, 82.7% were women and 17.3% men, with an average age of 22 years. In relation to their possible scientific background, we can highlight that 53.5% of the PSPs and 42.2% of the PSECs received their last training in science in the compulsory stage of secondary education.

Argumentation activity.

The argumentation-related activity presented in this paper formed part of a questionnaire that included other activities of a scientific nature. PSTs carried out the activity online. This activity is a clear example of how we can combine the four elements of argumentation (conclusion, evidence, warrant and refutation) with a chemical activity in accordance with the learning progression proposed by Osborne et al. (2016).

In this particular activity, only four levels of the critical dimension (identify evidence, provide a counter-critique, construct a one-sided or a two-sided comparative argument) and one level of the construction dimension (constructing a warrant) are addressed. The rest of the argumentation elements of the learning progression are covered with the set of activities proposed in the complete training programme.

The activity states that two fictitious students pour sugar into a glass of hot water and make three statements, presented as three pieces of evidence: "(1) Once the sugar is poured into the water, it is stirred. After stirring, the sugar can no longer be seen; (2) Also, after stirring, each student tastes the water. They both agree that the water tastes sweet; (3) The weight of

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the water + glass + sugar is the same as the weight of the glass containing the mixture after the sugar was stirred in" (Osborne et al. 2016). The activity also included a drawing showing a glass with sugar on a balance before and after stirring (figure 1).

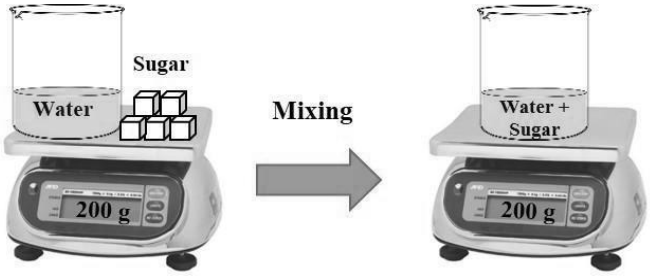

Figure 1. Drawing included in the activity (prepared by the authors).

The activity continues by providing the claims that the two students give when the teacher asks them if they think sugar remains in the water: "(1) Laura said: I think the sugar is gone and (2) Mary said: I think the sugar is still there".
It should be noted that the activity requires PSTs to draw on their scientific knowledge to construct and critique proposed links between conclusions and evidence. The activity also contained four questions to help PSTs elaborate on their arguments:
" (A) Choose an observation that supports what Mary says. Number: ___
(B) How does the observation you chose in part (A) support what Mary says?
(C) Which observation do you think best supports what Laura says? Number: ___
- This observation best supports Laura because_____
- The other two observations support Laura less because___
(D) Which student do you agree with more? Student name: ________
- I agree with this student more because...
- I agree with the other student less because..."

Researchers related each of the four questions (A, B, C and D) to the levels of learning progression proposed by Osborne et al. (2016). More specifically, in question A, the PSTs had to choose between three statements which could be identified with any of the three pieces of evidence presented previously (level 0d identify an evidence). Concerning question B, the PSTs had to construct a justification that supported the choice made in question A (level 1a, constructing a warrant). In question C, they had to demonstrate their ability to establish a critique of a given argument (level 2a, constructing a counter-critique). Finally, in question D, they had to be able to construct a critique of two well-differentiated arguments, which, in turn, can justify both arguments (level 2c, constructing a two-sided comparative argument).
Table 1 shows the rubric, used to analyse the responses, with the different levels of argumentation proposed by Osborne et al. (2016) and some examples of PSTs responses. The criteria for this rubric were established basing on Osborne's model and using student responses to shape the details of the criteria. During the analysis responses, it was necessarily made two additions to the rubric, such as:

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a) To include level 0d (identify evidence) as an intermediate level in question C.
b) To include level 2b (constructing a one-sided comparative argument) as an intermediate level in question D.

Table 1. Rubric adapted by researchers to evaluate the activity of argumentation about the dissolving process.

Questions	Level and criteria, adapted from Osborne et al. (2016)			Example of response
A		0	Observation 1.	--
	Identify evidence	0d	Observation 2 or 3.	--
B		0	He/she provides a justification that has nothing to do with or does not support what Mary says.	PSEC (341S) *"It is the observation that best supports Mary because she saw how the sugar was, but after stirring it, it disappeared."*
	Construct a warrant	1a	He/she provides a justification for the conservation of mass, and that sweetness is due to the sugar.	PSEC (125T) *"it can be seen from the weight that this does not vary after stirring the sugar, which leads us to think that the sugar remains in the water as Mary claims."*
C		0	He/she does not provide a counter-critique.	PSP (167E): *"The sugar is in there."*
	Identify evidence	0d	He/she provides observation 1 but does not justify it or does not provide the reason for the other two statements that do not support Laura's. It could also be that the contribution and the justifications here are wrong.	PSP (585F): *"If you do not see it, you might think it has gone. The second one says that there is still sugar and the last one is not related."* PSEC (988Y): *"When the sugar dissolves in the water, you do not see it, and she thinks it has gone. However, the sugar is still in the water, even though it is not visible."*
	Provide a counter-critique	2a	He/she provides observation 1 and justifies and provides the reason for the other two statements that do not support Laura's.	PSP (438B): *"When it is dissolved in the water, she thinks that it is not there, that is, she does not physically see it as when she poured it into the glass. She realises that it tastes sweet and observes that it weighs the same, even though the sugar is dissolved."*
D		0	He/she does not construct any comparative argument.	PSP (011D): *"Mary, because she thinks what is scientifically correct."*
	Construct a one-sided comparative argument	2b	He/she agrees with Mary but not with Laura but does not justify either one of them or justifies only one.	PSEC (618L): *"I agree more with Mary because it can be proved that the sugar is still there from the weight of the glasses. I disagree less because the sugar cannot disappear just like that."*
	Construct a two-sided comparative argument	2c	He/she agrees with Mary but not with Laura and justifies both.	PSP (154B): *"She says clearly that once the glass has been stirred, the sugar cannot be seen. One states that the taste is sweet, that is, that the sugar remains. The other observation states that the weight is the same, i.e. that the sugar is still in the glass, even if it is dissolved and not seen."*

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The researchers performed a statistical study of the responses to detect the possible existence of significant differences between groups. The sample size was greater than 50 cases; therefore, Kolmogorov-Smirnov-Lilliefors test was used to study normality. The data was not fitted to a normal distribution, so the non-parametric Mann-Whitney U test was employed to study differences between PSECs and PSPs since there are two independent samples. The analysis was performed using the SPSS statistics software version 21.0.

4. Results.

Figure 2 shows the percentages obtained for the highest level reachable for each question for all PSTs and the participants in each of the degrees. Moving through the different questions of the activity, which are related to an increasing difficulty in the ability to argue, the percentages for PSPs and PSECs gradually decreases. These data support the learning progression proposed by Osborne et al. (2016) in the sense of the difficulty experienced by PSTs as regards meeting the demands in each question of the activity.

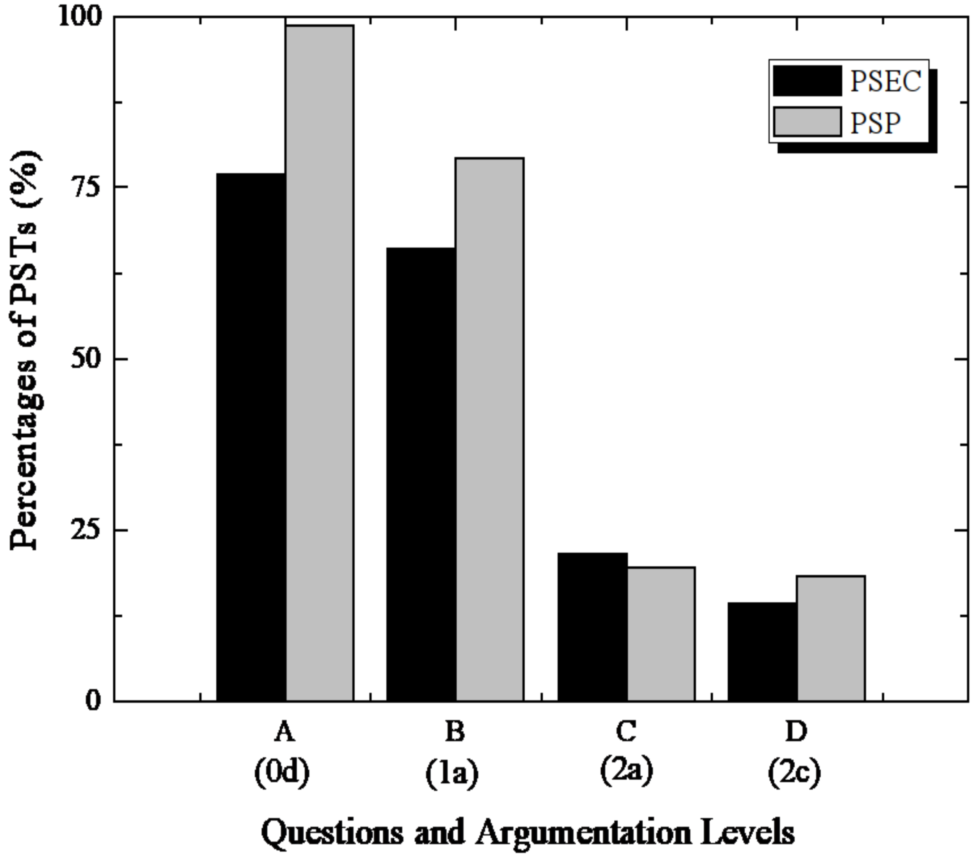

Figure 2. Percentages of PSTs for the highest levels in reachable each question.

Table 2 presents the results obtained for the percentage of PSTs studying each degree for all the levels in each question of the activity.

Table 2. Percentages for PSECs and PSPs at each level and question of the activity.

Question	Teachers	Osborne et al. (2016)'s levels						Mann-Whitney U Test	
		0	0d	1a	2a	2b	2c	U	p*
A	PSEC (%)	23.2	76.8					1683.5	0.000
	PSP (%)	1.3	98.7						
B	PSEC (%)	33.9		66.1				1872.5	NS
	PSP (%)	20.8		79.2					
C	PSEC (%)	37.5	41.1		21.4			2053.0	NS
	PSP (%)	29.9	50.6		19.5				
D	PSEC (%)	57.1				28.6	14.3	1928.0	NS
	PSP (%)	46.8				35.1	18.2		

* Statistically significant differences; NS: Non-Statistically significant differences

As shown in Table 2, the starting level of PSTs concerning identifying evidence (level 0d) is very appropriate since the percentages obtained for question A present values higher than 75% for PSTs from both degrees, being higher for PSPs (98.7%) than PSECs (76.8%). These results seem to indicate a similar starting level in both PSTs related to the ability to argue.
It makes sense if we consider that this question corresponds to the early level (0) of learning progress proposed by Osborne et al. (2016), where explicit connections between claims and evidence are not required. It means that it is possible to demonstrate competence with identification/critique of an isolated claim, warrant, or evidence without making a logical connection between them.
For question B, both degrees showed similar results, which again reveals the same level of assumption of PSECs and PSPs as regards their ability to construct a warrant (level 1a). It should be noted that, in this question, the highest percentages were found system in both groups (B2: PSEC 66.1%, PSP 79.2%) in this level. In this way, we can see that PSTs can establish one explicit logical connection between claim and evidence by way of a warrant, which Osborne et al. (2016) refer to as one degree of coordination.
As previously mentioned, in question C, the researchers included an intermediate level (0d), since in this question, the PSTs also carried out an identification of evidence (0d) prior to the construction of a counter-critique that would support their arguments (level 2a). The percentages obtained by the PSTs remain practically constant at this initial levels (level 0d) (PSEC 41.1%, PSP 50.6%).
It is necessary to emphasise that, in both cases, the percentages obtained for level 2a are around 20.0%. According to Osborne et al. (2016), it could indicate that PSTs are not still capable of criticising somebody else's argument, fully explain the claim that the argument is flawed and warrant why that argument is flawed, irrespective of the degree.

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Finally, as in the previous question, in the case of question D, the researchers also considered it appropriate to include an intermediate level, in this case level 2b since during the analysis of the responses, in some cases, the students only justified the argument they considered to be the best. In this case, we can see that the percentages, for levels 2b and 2c, remains below 40.0% in both degrees. It indicates that PSTs seem not to be able to make an evaluative judgment on two competing arguments and present an explicit argument concerning their respective worth, and they do not provide a warrant about why the other is weaker. It is important to note that for level 2c there is no significant difference in the percentages obtained for both degrees (14.3% for PSECs and 18.2% for PSPs). It may corroborate that the starting level for their competence in argumentation and critical thinking skills is similar for both PSTs. The Mann-Whitney U test did not show statistically significant differences between the two groups of PSTs for questions B, C and D, which seems to indicate that the starting level for their ability to argue was similar. However, it should be noted that, in question A, the Mann-Whitney U test found statistically significant differences between PSECs and PSPs, in favour of the latter, thus showing a better ability to identify evidence in this case.

5. Conclusions.

The research presented herein shows in response to RQ1 that the ability of PSPs and PSECs studying the subject of science education to argue is similar for a chemistry activity involving different levels of argumentation in terms of identifying evidence (level 0d), constructing a warrant (level 1a), providing a counter-critique (level 2a), and building a one-sided and a two-sided comparative argument (levels 2b and 2c). Also, the percentage of PSTs gradually decreases along with Osborne et al. (2016)'s learning progression, irrespective of their grade. We can assume in response to the main research question that PSTs have consolidated argumentation: to identify evidence (A) and to construct a warrant (B) since they are mainly located at the most adequate levels (0d and 1a). However, levels 2a, 2b and 2c are still not consolidated since they do not reach the maximum level for identifying evidence and providing a counter-critique (C) and constructing a one-sided comparative argument and constructing a two-sided comparative argument (D) respectively.

These results highlight the need to train PSTs at the higher levels of argumentation proposed by Osborne et al. (2016) (levels 2a, 2b and 2c). As such, we are developing a training programme for PSTs to learn how to argue in the field of chemistry. In addition, we can consider that this training programme should include one activity for each level of the argumentation ability learning progression and include activities to develop oral and written competence.

This work is a preliminary study, further research is needed with other argumentation activities to analyse not only written but also oral argumentation. In addition, it would be necessary to assess the argumentative capacity of the early child and primary school students in subsequent works.

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