Teachers’ attitudes towards the use of virtual simulations: Design and validation of a questionnaire

Actitud del profesorado hacia el uso de simulaciones virtuales: diseño y validación de un cuestionario

Alicia PALACIOS, PhD. Associate Professor. Universidad Internacional de La Rioja (UNIR), Spain (*alicia.palacios@unir.net*).
Rosa GÓMEZ, PhD. Associate Professor. Universidad Internacional de La Rioja (UNIR), Spain (*rosa.gomez@unir.net*).
Álvaro BARRERAS, PhD. Associate Professor. Universidad Internacional de La Rioja (UNIR), Spain (*alvaro.barreras@unir.net*).
Daniel MORENO-MEDIAVILLA, PhD. Associate Professor. Universidad Internacional de La Rioja (UNIR), Spain (*daniel.moreno@unir.net*).

Abstract:

Virtual simulations in science classes are not used as often as might be expected if we consider the demonstrated improvement in students’ conceptual learning, the development of their skills, and their acquisition of positive emotions. This makes it necessary to identify teachers’ attitudes and perceptions to the use of these tools. The aim of this work is to construct and validate an instrument for measuring the attitudes of secondary education teachers towards the use of virtual simulations in STEM fields. Based on an in-depth theoretical review, we developed an initial questionnaire that was subjected to a process of expert validation and a pilot study. A questionnaire comprising 27 items was obtained, which was applied to 783 secondary school teachers in Spain. After carrying out confirmatory factor analysis, a scale comprising five factors was obtained. The psychometric analyses displayed satisfactory fit indices that prove the discriminant and convergent validity of the model. The result is a useful instrument for determining the principal factors that discourage teachers from habitually using simulations. This enables the design of training proposals that take teachers’ prior attitudes into account.

Date of receipt: 2024-11-07.
Date of approval: 2024-04-10.
Please, cite this article as follows: Palacios, A., Gómez, R., Barreras, A., & Moreno-Mediavilla, D. (2024). Teachers’ attitudes towards the use of virtual simulations: Design and validation of a questionnaire [Actitud del profesorado hacia el uso de simulaciones virtuales: diseño y validación de un cuestionario]. *Revista Española de Pedagogía, 82* (289), 585-605. https://doi.org/10.22550/2174-0909.4165

Keywords: virtual simulations, teacher attitude, questionnaire, secondary teaching.

Resumen:

Las simulaciones virtuales en el aula de ciencias no se utilizan de manera tan habitual como cabría esperar si se tiene en cuenta la mejora demostrada en el aprendizaje conceptual del estudiante, en el desarrollo de sus habilidades y en la adquisición de emociones positivas. Esto hace necesario conocer cuáles son las actitudes y percepciones del profesorado en el uso de estas herramientas. El objetivo de este trabajo es construir y validar un instrumento de medida de las actitudes del profesorado de educación secundaria hacia el uso de simulaciones virtuales de áreas STEM. A partir de una profunda revisión teórica, se desarrolló un cuestionario inicial, que fue sometido a un proceso de validación de expertos, y un estudio piloto. Se obtuvo un cuestionario formado por 27 ítems, el cual fue aplicado a 783 profesores de educación secundaria de España. Tras el análisis factorial confirmatorio desarrollado, se obtuvo una escala compuesta por cinco factores. Los análisis psicométricos mostraron índices de ajuste satisfactorios que prueban la validez discriminante y convergente del modelo. El resultado es un instrumento útil para determinar los factores principales que alejan al profesorado del uso habitual de las simulaciones. Esto posibilita el diseño de propuestas de formación que tengan en cuenta las actitudes previas del docente.

Palabras clave: simulaciones virtuales, actitud del docente, cuestionario, enseñanza secundaria.

1. Introduction

In current science teaching focuses, the learning of processes and understanding of content are becoming ever more important. Given this need, new technological challenges that favour a holistic learning of science are emerging (Oliverira et al., 2019; Osborne, 2014). In this sense, virtual simulations (VS) offer strategies based on the scientific method (De Jong & Van Joolingen, 1998; Fan & Geelan, 2013; Rutten et al., 2012), which favour reasoning and inquiry competences (Stieff, 2019; Trujillo et al., 2023; Wen et al., 2020), graphical competences (Plass et al., 2012), higher-order thinking skills (Amin & Ikhsan, 2021), and scientific literacy (Chen et al., 2014; Lynch & Ghergulescu, 2017). Furthermore, they have the capacity to support model-based learning and its effect on visualisation (Lee et al., 2021) of most of the content associated with STEM (science, technology, engineering, and mathematics) fields (D'Angelo et al., 2014). They also make it possible to represent real phenomena: students observe and manipulate variables and phenomena, and visualise the changes that occur (Chan et al., 2021; De Jong & Van Joolingen, 1998). Finally, the use of virtual simulations improves students' satisfaction and engagement (Durán et al., 2007; Wu & Huang, 2007), and so they develop positive attitudes towards the sciences (Zacharia, 2003).

All of these characteristics make the introduction of virtual simulations as a didactic resource very beneficial (D'Angelo et al., 2014; Waight et al., 2014). However, they are not habitually used in classrooms (Chan et al., 2021; Lee et al., 2021). To resolve this situation, a need to work from two fundamental perspectives emerges: teachers' knowledge of the use of virtual simulations (Gómez et al., 2022; Moreno-Mediavilla et al., 2023) and their attitude towards using them (Lee et al., 2021). The aim of the present work relates to this latter perspective.

Attitude is described as an individual's favourable or unfavourable outlook on an object, a person, or an event (Albirini, 2006). This is a multidimensional construct that encompasses three dimensions (affective, behavioural, and cognitive) although their inclusion and interpretation vary according to the authors. For example, Teo et al. (2016) include the affective dimension, understood as teachers' enjoyment of, pleasure from, and preference for the use of technology. Shapka and Ferrari (2003) also add the factor of anxiety when using technology. Not all authors regard the behavioural dimension as relevant. However, Teo (2008) does consider it to be important, as it makes it possible to analyse how proactive teachers are towards different technological resources, their regular use, and training. The cognitive dimension is associated with aspects such as perceived time savings or the improvements that technology provides in the educational process (Albirini, 2006). Other cognitive components are also included, such as teachers' perception of the usefulness of resources or their skills in using them (Teo, 2008), or the beliefs, valuation, and social function that they give to the use of technology (Cai et al., 2017).

Based on these definitions, many authors have analysed the principal variables that affect the use of technology in education, drawing on the TAM theoretical model (technology acceptance model) (Davis et al., 1989). According to this model, the perceived usefulness and ease of use of technology significantly influence attitudes towards using it, and this is related to the intention to use the technology and its actual use (Albirini, 2006; Tate et al., 2015; Teo et al., 2016). In addition to these two principal factors, other possible variables have been described: the conditions that facilitate the use of technology (Lai et al., 2012; Teo, 2012), technological complexity (Teo, 2012), teacher self-efficacy (Wong et al., 2012), gender (Cai et al., 2017), age (Nunes et al., 2020), years of experience of use (Gargallo et al., 2007), and field of study (Teo, 2008).

The extensive bibliography on attitudes towards the use of technology contrasts with the few works on attitudes towards the specific use of virtual simulations. Zacharia (2003) noted that teachers' attitudes towards the use of technology improved after using it in class. For their part, Lehtinen et al. (2016) showed that knowledge of technology is correlated with the perceived usefulness of simulations and with attitudes towards their use in class. Recently, Lee et al. (2021) analysed teachers' attitudes towards the use of simulations through interviews. They found that the principal variables were perceived usefulness, ease of use, appropriateness of the simulations, the possibility of engaging students in learning, and the teacher's professional growth needs. With regards to the use of virtual simulations by teachers, Gómez et al. (2022) and Moreno-Mediavilla et al. (2023) designed and administered a questionnaire to analyse the perception of teachers' perception of their digital competence in the actual use of virtual simulations. The questionnaire presented in this work provides information of great interest for addressing teachers' specific attitudes towards the use of virtual simulations, as there is no specific instrument for evaluating them. The attitudes and beliefs of the teacher on the use of these tools are decisive for improving their willingness to use them (Khan, 2011; Padilla, 2018). As well as identifying teachers' attitudes towards the use of virtual simulations, this questionnaire establishes whether this attitude directly influences the use of such tools and compares it with teachers' own perceptions of their digital competences. This question has been highlighted as one of the principal needs in teacher training, as noted by De Pro Bueno et al. (2022) and Pozuelo et al. (2023).

Given the importance of knowing teachers' attitudes towards the implementation of virtual simulations in the classroom, this work aims to design and validate a questionnaire on secondary teachers' attitudes towards the use of virtual simulations in STEM.

2. Method

2.1. Research design

This study is quantitative, non-experimental, and descriptive and uses a transversal design.

2.2. Sample

The sample was obtained using non-probability convenience sampling. It consists of 783 secondary education teachers from Physics, Chemistry, Biology, Geology, Technology, and Mathematics from all over Spain, who work in public (80.72%), state assisted (16.22%), and private (3.07%) schools in urban (73.56 %) and rural (26.44%) areas. Of the participants, 61.94 % are women and 37.68% men. In relation to age, 8.43% of the teachers are aged under 31; 20.05%, between 31 and 40; 37.42%, between 41 and 50; 31.42%, between 51 and 60, and 2.68% of them are more than 60 years old. With regards to the distribution of years of teaching experience, 22.09% have less than 5 years of experience, 17.24% have between 5 and 10 years, 24.39% have between 11 and 20 years, and 36.27% have more than 20 years' teaching experience.

2.3. Process of preparation of the questionnaire

The process of preparing this instrument takes as its starting point, the TAM model of Davis et al. (1989), who suggest that the usefulness and ease of use of technologies directly influence people's attitudes and, with it, their final behaviour. Therefore, the questionnaire proposes an initial model with two major factors (usefulness and ease of use). In addition, other variables that might influence the use of technologies and, in particular, virtual simulations were taken into account for the design of the items (Lee et al., 2021, Albirini, 2006, Teo et al., 2016, Tate et al., 2015). So, items related to the affective dimension of the attitude towards the use of virtual simulations were proposed, like those previously described by Teo et al. (2016). Likewise, items were defined that relate to perceived usefulness and are widely described by various authors (Albirini, 2006; Sahin et al., 2016; Teo, 2008; Teo et al., 2016). These items were proposed considering two additional aspects: their usefulness for improving understanding of content and their usefulness for acquiring scientific competences. Finally, in line with the need proposed by Lee et al. (2021) to consider in depth the aspects involved in teachers' perceptions of the ease of use of simulations, items that relate to their availability, complexity of use, and possible obstacles for students' learning were introduced.

Through this analysis, 46 relevant items were identified for the first version of the instrument. With the aim of determining the content validity of the questionnaire, a process of expert judgement was carried out by a panel of 4 teachers and researchers [an adequate number according to Grant and Davis (1997)] selected by convenience. These professionals had a variety of professional experience (from 10 to 46 years) and were experts of recognised standing in the didactics of experimental sciences, didactics of mathematics, and research methods in education. The judgement they provided included analysis of each item in relation to three properties: clarity, coherence, and relevance, as well as the relevant comments for each case. In cases where two or more experts negatively evaluated the coherence or relevance properties, the item was eliminated; when clarity was criticised, the item's wording was reviewed.

A pilot trial was then carried out with a sample of 30 secondary education teachers from STEM fields in Spain, selected by convenience sampling; the objective of this was to obtain information about the relevance of the items. The teachers were from public and state-assisted centres in urban and rural locations. The questionnaire was distributed by email during the first two weeks of October 2021. A Cronbach's alpha analysis of the questionnaire as a whole was performed and the item-total correlation was analysed.

2.4. Instrument and data collection procedure

The CADUSV questionnaire (Teacher Attitudes to the Use of Virtual Simulations Questionnaire), drawn up using the Survey Monkey tool, includes several questions to characterise the sample (sex, age, years of teaching experience, speciality, and type of educational centre) and 27 items relating to the attitudes of STEM teachers towards the use of virtual simulations (link to the questionnaire). The teachers indicate their level of agreement or disagreement with each item on a Likert scale from 1 to 5. In addition, the objective of the study is set out in the instrument and the participation of teachers of Physics and Chemistry, Biology and

Geology, and Technology and Mathematics in secondary education is requested.

The questionnaire was distributed manually by email to public, state-assisted, and private educational centres in Spain. It was distributed between the second half of January and the end of February 2022 during which period participation in this study was active. Participants' anonymity was ensured at all moments.

2.5. Data analysis

The existence of previous studies directly related to the topic made it possible to start from a series of factors when constructing the questionnaire. Therefore, the construct validation was done through confirmatory factor analysis (CFA), for which the Mplus 8.1.5 data analysis program was used.

Using the SPSS 25 program, the samples were first checked for the presence of outliers; any found were eliminated from the total sample. The assumption of multivariate normality was tested using the Mardia coefficient (1970), which is determined based on the skew and kurtosis figures. As this assumption was not fulfilled, the polychoric matrix was used as the basis of the CFA. With the aim of fully rejecting the option of using the Pearson matrix as the basis of the analysis, tests were carried out with both types of matrix. In the case of the Pearson matrix, worse fit figures were observed. The estimate of the models was developed using the unweighted least squares mean and variance adjusted (ULSMV) estimator, given that the variables observed for the proposed model were ordinal.

The indices of fit of the two-dimensional model were calculated first and the modification indices and standardised residuals were obtained with the aim of improving the fit of the models. Absolute fit indices, which make it possible to evaluate whether the underlying theory fits the data extracted, were used as well as incremental fit indices, which compare the proposed model to a base model (McNeish et al., 2018).

The following absolute fit indices were obtained: the chi-squared value divided by the degrees of freedom for the model (CMIN/*df*), where values below 2 are very good and between 3 and 5 are acceptable (Hair et al., 2014); and the root mean square error of approximation (RMSEA), which seeks to test the fit between the proposed model and hypothetical population-al data. In this case, values below .05 are considered very good, and between .05 and .08, acceptable (Byrne, 2009). The incremental fit indices provided are CFI (comparative fit index) and TLI (Tucker–Lewis index). In these, values greater than .9 are adequate and from .95 they are considered optimal (Xia & Yang, 2019).

With the aim of determining the discriminant validity, the two-factor model was analysed and was compared with the single-factor model, as well as with the four, five, and six factor models. The existence of second-order models was also considered (Table 1). These alternative models were defined on the basis of different possible combinations that were consistent with the theoretical assumption described above. For the comparison of the models, the indices of fit specified above were studied.

TABLE 1. Organisation of the different models regarding items and factors.

Item	2f model	4f model	5f model	6f model	5f model with second-order factors		6f model with second-order factors	
1								
2								
3				Perceived usefulness for conceptual learning (PUConc)			Perceived usefulness for conceptual learning (PUConc)	
4								
5			Perceived usefulness (PU)		Perceived usefulness (PU)			
6								
7	Interest in use (IU)	Interest in use (IU)				Factor 1: interest in use (IU)		Factor 1: interest in use (IU)
8				Perceived usefulness for competence learning (PUComp)			Perceived usefulness for competence learning (PUComp)	
9								
10								
11								
12*			Beliefs and feelings about the use of VS (BFU)	Beliefs and feelings about the use of VS (BFU)	Beliefs and feelings about the use of VS (BFU)		Beliefs and feelings about the use of VS (BFU)	
13								
14								

Revista Española de Pedagogía
year 82, n. 289, September-December 2024, 585-605

15	Perceived difficulty (PD)					Factor 2: perceived difficulty (PD)		Factor 2: perceived difficulty (PD)
16		Complexity of use (CU)	Complexity of use (CU)	Complexity of use (CU)	Complexity of use (CU)		Complexity of use (CU)	
17								
18								
19								
20								
22		Obstacles for learning (OL)	Obstacles for learning (OL)	Obstacles for learning (OL)	Obstacles for learning (OL)		Obstacles for learning (OL)	
23								
25								
26		Availability (A)	Availability (A)	Availability (A)	Availability (A)		Availability (A)	
27								

*Item 12, in the initial analyses, belongs to the *perceived difficulty* dimension, as explained in the results section.

Also, to determine the shared variance of the items that form a dimension the convergent validity was analysed by analysing the factor loadings, which must achieve values greater than .5. Within the convergent validity, composite reliability was also analysed (Green & Yang, 2015) as well as the average variance extracted (AVE). To be considered acceptable, these values must be above .7 and .37-.5, respectively (Hair et al., 2014; Moral, 2019).

3. Results

The initial model proposed for validation comprised 27 observed variables and two latent dimensions: interest in use (IU) and perceived difficulty (PD) (Table 1).

The analysis of outliers revealed the existence of six data sets that had to be eliminated, and so the final study sample comprised 777 teachers, 99% of the initial sample. After establishing that the assumption of multivariate normality of Mardia was not fulfilled (Table 2) and that the fit with the Pearson matrix did not generate satisfactory results, it was decided to use the polychoric correlation matrix for the CFA.

We initially started from the estimate of the model of two dimensions (IU and PD) to then improve it based on the R^2 values and the modification indices of each item. As Table 3 shows, almost all of the R^2 values were greater than .5, and so they were considered to be items that were adequate for explaining the model. However, it was decided that items 21 and 24, with R^2 values close to zero, did not have explanatory power and so they were eliminated from the questionnaire.

Table 2. Mardia analysis.

	Coefficient	Statistic	*df*	*p*
Skew	67.269	8711.274	3654	1.000
Adjusted skew for small samples	67.269	8.747.318	3654	1.000
Kurtosis	924.526	49.845		.000*

Note: the significance level considered is 5%.

TABLE 3. Original model (2 dimensions).

Variable	Factorial weight	SE	*p*-value	R^2
1	.880	.016	0	.774
2	.854	.019	0	.729
3	.783	.017	0	.614
4	.806	.018	0	.649
5	.732	.021	0	.536
6	.818	.018	0	.670
7	.814	.018	0	.663
8	.612	.025	0	.374
9	.719	.021	0	.517
10	.780	.018	0	.609
11	.838	.016	0	.703
12	-.817	.024	0	.668
13	.739	.019	0	.546
14	.858	.015	0	.735
15	.471	.035	0	.222
16	.452	.033	0	.204
17	.692	.029	0	.479
18	.614	.032	0	.377
19	.569	.034	0	.324
20	.653	.031	0	.426
21	**-.099**	**.039**	**.01**	**.010**
22	.501	.034	0	.251
23	.579	.032	0	.336
24	**.131**	**.041**	**.001**	**.017**
25	.680	.026	0	.463
26	.510	.032	0	.260
27	.551	.031	0	.303

Based on the modification indices, it was observed that item 12 better fitted the *interest in use* (IU) dimension, and so the decision was taken to move it to this dimension. The analysis of the modification indices showed the existence of correlations between the errors from items 22 and 23, items 7 and 8, and items 26 and 27, which were included. As Table 4 shows, with the changes made to the model with two dimensions, a notable but insufficient improvement in the fit values was obtained.

Next, various models were tested that matched the different theoretical assumptions explored: 1 dimension, 4 dimensions, 5 dimensions, 6 dimensions, and 5 and 6 dimension models with second-order factors (see Tables 1 and 4).

As for the fit of these models, it was found that items 19 and 22 always displayed inadequate R^2 values and that the modification indices displayed the same change in item 12. For this reason, all of the models include these modifications.

TABLE 4. Comparison of all of the models studied

	X^2	*df*	*p*	X^2/df	**RMSEA**	**RMSEA** (*p*)	**CGI**	**TLI**
2 factors (original)	2493	323	0	7.718	.093	0	.837	.822
2 factors	1274.986	271	0	4.705	.069	0	.923	.914
1 factor	3631.954	272	0	13.353	.126	0	.741	.714
4 factors	1208.161	267	0	4.525	.067	0	.927	.918
5 factors	974.259	263	0	3.704	.059	0	.945	.937
5 factors + 2 second order factors	1028.209	268	0	3.837	.060	0	.941	.935
6 factors	965.907	258	0	3.744	.059	0	.945	.937
6 factors + 2 second order factors	1113.053	267	0	4.169	.064	0	.935	.927

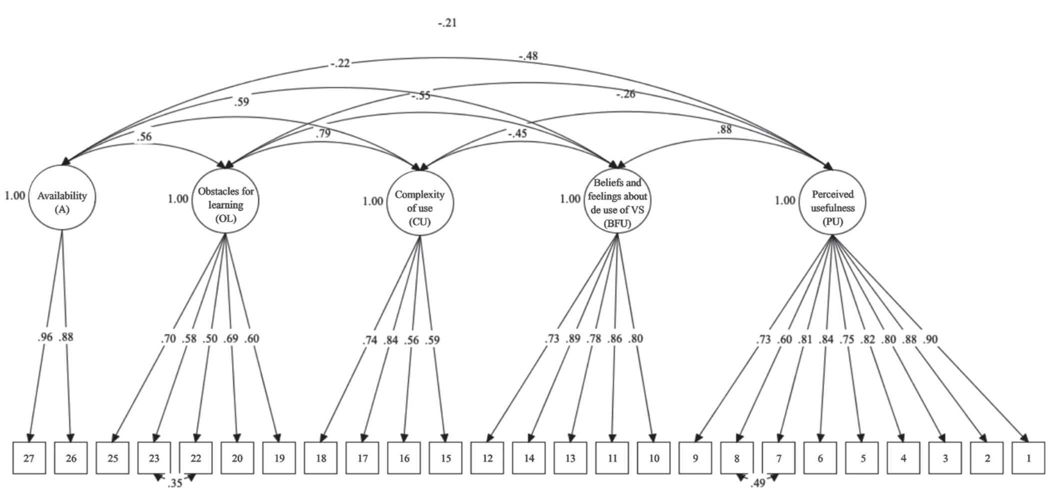
On this point, it should be noted that, in all of the models, the correlations between the factors were defined as free parameters. To analyse the discriminant validity of the model, Table 4 shown a comparison of the indices of fit for the different models tested. The calculated indices of fit show that the one-dimensional structure of the questionnaire should be rejected. The values of χ^2/df, RMSEA, CFI, and TLI do not indicate a clear improvement in fit when we move from the 2-dimension model (IU and PD) to the one with 4 dimensions (IU, CU, OL, and A). However, a clear improvement in fit is observed when comparing the 2-dimension model with the 5-dimension model (PU, BFU, CU, OL, A). With this latter model, a RMSEA value very close to .05 is obtained as well as CFI and TLI values greater than .93, something that indicates an adequate fit of the model. The 6-dimension model (PUConc, PUComp, BFU, CU, OL, A) also has adequate fit; the theoretical justification is that the 5 and 6 dimension models only differ in the subdivision of the PU dimension into PUConc and PUComp. However, there is no improvement in the indices of fit compared to the 5-dimension model. Finally, with regards to models with 5 and 6 dimensions with second-order factors, there is a small improvement in the incremental fit indices but the absolute fit indices become slightly worse and so no relevant overall improvement is observed. Therefore, the analysis of discriminant validity and the principle of parsimony (Carroll, 1978; Ferrando & Anguiano-Carrasco, 2010) indicate that the model which is simplest and offers the best fit to the theoretical principles is the five factor model: *perceived usefulness* (PU), *beliefs and feelings about the use of VS* (BFU), *complexity of use* (CU), *obstacles for learning* (OL), and *availability* (A). In this model, the two initial dimensions of IU and PD have been subdivided into two and three, respectively. In this way, more concrete dimensions are obtained that provide valuable information about the aspects that affect teachers' attitude towards the use of simulations (Table 5). Figure 1 shows the outline of the final five factor model of the CADUSV questionnaire, in which a correlation was established between the errors from items 7 and 8 and items 22 and 23 based on what is shown by the modification indices of the model.

TABLE 5. Five factor model.

	Factorial weight	**SE**	***p*-value**	R^2
Perceived usefulness				
Item 1	.899	.015	0	.808
Item 2	.876	.018	0	.767
Item 3	.802	.017	0	.643
Item 4	.824	.018	0	.679
Item 5	.746	.021	0	.557
Item 6	.838	.017	0	.702
Item 7	.813	.018	0	.661
Item 8	.602	.026	0	.362
Item 9	.734	.02	0	.539
Beliefs and feelings about the use of virtual simulations				
Item 10	.804	.018	0	.646
Item 11	.865	.016	0	.748

Item 12	.731	.021	0	.534
Item 13	.775	.017	0	.601
Item 14	.891	.014	0	.794
Complexity of use				
Item 15	.59	.033	0	.348
Item 16	.558	.034	0	.311
Item 17	.84	.028	0	.706
Item 18	.742	.03	0	.551
Obstacles for learning				
Item 19	.6	.033	0	.360
Item 20	.692	.032	0	.479
Item 22	.5	.035	0	.250
Item 23	.58	.033	0	.336
Item 25	.701	.029	0	.491
Availability				
Item 26	.876	.021	0	.767
Item 27	.956	.022	0	.914

Figure 1. Summary outline of the final 5-factor model.



To determine the convergent validity of the 5-factor model, it should be noted that the factor loadings of all of the items are greater than .5 (Table 5). Furthermore, Table 6 shows the results for composite reliability and average variance extracted for the different models, which confirm that the 5-factor model is the most satisfactory in overall terms. The PU, BFU, and A factors display an omega reliability greater than .9 and a mean explained variance much greater than .5. The CU factor displays an omega reliability greater than .7 and an AVE very close to .5 (.479). Finally, the OL factor also displays an omega reliability greater than .7, but an AVE on the limit of what is considered to be acceptable (.37-.5) according to Moral (2019).

TABLE 6. Convergent validity.

Number of factors	Name of factor (initials)	AVE	Omega reliability
1 factor	Attitudes towards use (AU)	.385	.734
2 factors	Interest in use (IU)	.607	.955
	Perceived difficulty (PD)	.335	.854
4 factors	Interest in use (IU)	.607	.955
	Complexity of use (CU)	.478	.781
	Obstacles for learning (OL)	.384	.754
	Availability (A)	.840	.913
5 factors	Perceived usefulness (PU)	.635	.939
	Beliefs and feelings about the use of VS (BFU)	.665	.908
	Complexity of use (CU)	.479	.781
	Obstacles for learning (OL)	.383	.754
	Availability (A)	.841	.913
5 factors + 2 second order factors	Perceived usefulness (PU)	.635	.939
	Beliefs and feelings about the use of VS (BFU)	.665	.908
	Complexity of use (CU)	.479	.782
	Obstacles for learning (OL)	.385	.754
	Availability (A)	.840	.913
	F1: interest in use (IU)	.890	.942
	F2: perceived difficulty (PD)	.666	.851

6 factors	Perceived usefulness for conceptual learning (PUConc)	.698	.933
	Perceived usefulness for competence learning (PUComp)	.618	.827
	Beliefs and feelings about the use of VS (BFU)	.665	.908
	Complexity of use (CU)	.479	.781
	Obstacles for learning (OL)	.384	.754
	Availability (A)	.841	.913
6 factors + 2 second order factors	Perceived usefulness for conceptual learning (PUConc)	.698	.933
	Perceived usefulness for competence learning (PUComp)	.711	.827
	Beliefs and feelings about the use of VS (BFU)	.664	.908
	Complexity of use (CU)	.479	.782
	Obstacles for learning (OL)	.385	.754
	Availability (A)	.841	.913
	F1: interest in use (IU)	.859	.948
	F2: perceived difficulty (PD)	.666	.851

4. Discussion and conclusions

In the present research, a specific questionnaire on teachers' beliefs and attitudes towards the use of virtual simulations was designed and validated to consider in greater depth the main aspects that encourage or discourage teachers from using this tool.

The design of the questionnaire started from the principal factors that influence the use of technologies, such as their usefulness and the ease or complexity of their use (Davis et al., 1989). In addition to these factors, variables described as shaping the behaviour of the teacher were introduced, both in the general use of technologies (Albirini, 2006; Sahin et al., 2016; Teo, 2008; Teo et al., 2016), and in the specific use of virtual simulations (Lee et al., 2021; Zacharia, 2003).

The questionnaire, which initially comprised 46 items, was optimised following the expert judgement and the pilot trial giving a final composition of 27 items. Following the CFA carried out in this work, which starts form an initial two-factor model (*interest in use* and *perceived difficulty*), a scale comprising five factors was obtained: *perceived usefulness* (PU), comprising 9 items; *beliefs and feelings* towards the use of SV (BFU), comprising 5 items; *complexity of use* (CU), which includes 4 items; *obstacles for learning* (OL), with 5 items; and *availability* (A), which contains 2 items. The division of the *interest in use* theoretical dimension into two factors (PU and BFU) is theoretically based on the differentiation between the aspects referring to the teacher's beliefs regarding the usefulness of virtual simulations (Teo, 2008; Teo et al., 2016) and the effective aspects relating to the emotions of the teacher on the use of SV, previously described by Albirini (2006) or Lee et al. (2021). With regards to the *perceived difficulty* theoretical dimension, this is divided into three factors (CU, OL, and A) because this difficulty, as Lee et al. (2021) previously noted, can have different origins. The results of this work indicate that there are at least three factors that might discourage teachers: complexity of use, previously defined by Teo (2008); availability, closely related to the concept of accessibility studied by Hew and Brush (2007); and obstacles to learning, that is to say, the characteristics described regarding virtual simulations and their use. This five-factor structure provides a greater specificity when analysing teachers' beliefs and attitudes towards the use of virtual simulations and so it can help to identify the decisive factors that encourage or discourage science teachers in the use of virtual simulations in their classrooms.

The quality of the questionnaire has been proven through CFA, providing indices of fit that prove the discriminant validity of the 5-factor model. The convergent validity showed satisfactory values for all of the dimensions apart from OL, where despite it having adequate composite reliability values, the AVE values were on the limit of what is acceptable according to Moral (2019), and so it would be interesting to evaluate this dimension to improve its convergent validity in future works. The *availability* (A) dimension displays only two items, and so, despite presenting adequate validity values, it would be interesting to analyse it in greater depth. We consider that these limitations of the questionnaire derive from the very theoretical design of its items. Even though the questionnaires on teachers' attitudes towards the use of technology that we identified were used as a basis, the small number of works published on teachers' attitudes towards the specific use of virtual simulations (Lee et al., 2021; Lehtinen et al., 2016; Zacharia, 2003) and the lack of previous questionnaires in this field hampered the design of the items and dimensions of the questionnaire.

Another limitation of the study relates to the use of non-probability convenience sampling. It would be interesting to administer this questionnaire in future works to a larger sample obtained by means of probability sampling to confirm its validity and improve it.

Overall, the statistical results confirm the validity of the theoretical construct, and so the CADUSV questionnaire appears to be a useful and practical instrument for analysing teachers' attitudes towards the use of virtual simulations in STEM subjects. Knowledge of this perception is vital to determine the main factors that push teachers away from habitually using this resource, as their perceptions of and attitudes towards technologies directly influence their effective use (Paraskeva et al., 2008). Identifying these factors is also of great interest for designing personalised training proposals that take into account the prior attitudes and beliefs of the teacher (Gargallo, et al., 2006; Padilla, 2018). As Lee et al. (2021) and Pozuelo et al. (2023) already noted, it is necessary to resolve the possible demands or difficulties that teachers face when using virtual simulations to improve their attitude and so increase the effective use of this tool in science teaching.

Authors' contributions

Alicia Palacios: Formal analysis; Investigation; Methodology; Software; Writing (original draft); Writing (review and editing).

Rosa Gómez: Formal analysis; Investigation; Methodology; Software; Writing (original draft); Writing (review and editing).

Álvaro Barreras: Data curation; Investigation; Methodology; Software; Writing (original draft); Writing (review and editing).

Daniel Moreno-Mediavilla: Conceptualization; Investigation; Methodology; Project administration; Writing (originaldraft); Writing (review and editing).

Funding

This study has been funded by a research project of the Universidad Internacional de La Rioja (UNIR): Proyecto-Propio UNIR2022.

Acknowledgements

We would like to thank the panel of experts and the teachers who took part in this study.

References

Albirini, A. (2006). Teachers' attitudes toward information and communication technologies: The case of Syrian EFL teachers. *Computers & Education*, *47* (4), 373–398. https://doi.org/10.1016/j.compedu.2004.10.013

Amin, D. I., & Ikhsan, J. (2021). Improving higher order thinking skills via semi second life. *European Journal of Educational Research*, *10* (1), 261-274. https://doi.org/10.12973/eu-jer.10.1.261

Cai, Z., Fan, X., & Du, J. (2017). Gender and attitudes toward technology use: A meta-analysis. *Computers & Education*, *105*, 1-13. https://doi.org/10.1016/j.compedu.2016.11.003

Carroll, J. B. (1978). How shall we study individual differences in cognitive abilities? Methodological and theoretical perspectives. *Intelligence*, *2* (2), 87-115. https://doi.org/10.1016/0160-2896(78)90002-8

Chan, P., Van Gerven, T., Dubois, J., & Bernaerts, K. (2021). Virtual chemical laboratories: A systematic literature review of research, technologies and instructional design. *Computers and Education Open*, *2*, 100053. https://doi.org/10.1016/j.caeo.2021.100053

Chen, S., Chang, W., Lai, C., & Tsai, C. (2014). A comparison of students' approaches to inquiry, conceptual learning, and attitudes in simulation-based and microcomputer-based laboratories. *Science Education*, *98* (5), 905-935. https://doi.org/10.1002/sce.21126

D'Angelo, C., Rutstein, D., Harris, C., Bernard, R., Borokhovski, E., & Haertel, G. (2014). *Simulations for STEM learning: Systematic review and meta-analysis*. SRI Ecucation.

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management science*, *35* (8), 982-1003. https://doi.org/10.1287/mnsc.35.8.982

De Jong, T., & Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research*, *68* (2), 179-201. https://doi.org/10.3102/00346543068002179

de Pro, A., de Pro, C., & Cantó, J. (2022). Cinco problemas en la formación de maestros y maestras para enseñar ciencias en Educación Primaria. *Revista Interuniversitaria de Formación del Profesorado*, *97* (36.1), 185-202. https://doi.org/10.47553/rifop.v97i36.1.92510

Durán, M. J., Gallardo, S., Toral, S. L., Martínez-Torres, R., & Barrero, F. J. (2007). A learning methodology using Matlab/Simulink for undergraduate electrical engineering courses attending to learner satisfaction outcomes. *International Journal of Technology and Design Education*, *17* (1), 55-73. https://doi.org/10.1007/s10798-006-9007-z

Fan, X., & Geelan, D. (2013). Enhancing students' scientific literacy in science education using interactive simulations: A critical literature review. *Journal of Computers in Mathematics and Science Teaching*, *32* (2), 125-171.

Ferrando, P. J., & Anguiano-Carrasco, C. (2010). El análisis factorial como técnica de investigación en psicología [Factor analysis as a research technique in psychology]. *Papeles del Psicólogo*, *31* (1), 18-3. https://www.papelesdelpsicologo.es/pdf/1793.pdf

Gargallo, B., Suárez, J., & Almerich, G. (2006). La influencia de las actitudes de los profesores en el uso de las nuevas tecnologías. **Revista Española de Pedagogía**, *64* (233), 45-66.

Gómez, R., Palacios, A., Moreno-Mediavilla, D., & Barreras, Á. (2022). Competencias docentes en el uso de simulaciones virtuales STEM: diseño y validación de un instrumento de medida (CDUSV) [Teacher competences in the use of STEM virtual simulations: design and validation of a measurement instrument (CDUSV)]. Bordón, *Revista de Pedagogía, 74* (4), 85-102.

Grant, J. S., & Davis, L. L. (1997). Selection and use of content experts for instrument development. *Research in Nursing* y *Health*, *20* (3), 269-274. https://doi.org/10.1002/(SICI)1098-240X(199706)20:3%3C269::AID-NUR9%3E3.0.CO;2-G

Green, S. B., & Yang, Y. (2015). Evaluation of dimensionality in the assessment of internal consistency reliability: Coefficient alpha and omega coefficients. *Educational Measurement: Issues and Practices*, *34* (4), 14-20. https://doi.org/10.1111/emip.12100

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2018). *Multivariate data analysis* (8.ª ed.). Cengage Learning.

Hew, K. F., & Brush, T. (2007). Integrating technology into K-12 teaching and learning: Current knowledge gaps and recommendations for future research. *Educational Technology Research and Development*, *55* (3), 223-252. https://doi.org/10.1007/s11423-006-9022-5

Khan, S. (2011). New pedagogies on teaching science with computer simulations. *Journal of Science Education and Technology*, *20* (3), 215-232. https://doi.org/10.1007/s10956-010-9247-2

Lai, C., Wang, Q., & Lei, J. (2012). What factors predict undergraduate students' use of technology for learning? A case from Hong Kong. *Computers & Education*, *59* (2), 569-579. https://doi.org/10.1016/j.compedu.2012.03.006

Lee, W. C., Neo, W. L., Chen, D. T., & Lin, T. B. (2021). Fostering changes in teacher attitudes toward the use of computer simulations: Flexibility, pedagogy, usability and needs. *Education and Information Technologies*, *26* (4), 4905-4923. https://doi.org/10.1007/s10639-021-10506-2

Lehtinen, A., Nieminen, P., & Viiri, J. (2016). Preservice teachers' TPACK beliefs and attitudes toward simulations. *Contemporary Issues in Technology and Teacher Education*, *16* (2), 151-171.

Lynch, T., & Ghergulescu, I. (2017). Review of virtual labs as the emerging technologies for teaching STEM subjects. En L. Gómez, A. López, & I. Candel (Eds.), *INTED2017 Proceedings. 11th International Technology, Education and Development Conference. March 6th-8th, 2017 - Valencia, Spain* (pp. 6082-6091). IATED Academy. https://doi.org/10.21125/inted.2017.1422

Mardia, K. V. (1970). Measures of multivariate skewnees and kurtosis with applications. *Biometrika*, *57* (3), 519-530. https://doi.org/10.2307/2334770

Moral, J. (2019). Revisión de los criterios para validez convergente estimada a través de la varianza media extraída [Review of the criteria for convergent validity estimated through the extracted average variance]. *Psychología*, *13* (2), 25-41. https://revistas.usb.edu.co/index.php/Psychologia/article/view/4119

Moreno-Mediavilla, D., Palacios-Ortega, A., Gómez, R., & Barreras-Peral, A. (2023). Competencia digital docente en el uso de simulaciones virtuales: percepción del profesorado de áreas STEM [Teacher digital competence in the use of virtual simulations: STEM teachers' perception]. *Pixel-Bit. Revista de Medios y Educación*, (68), 83-113. https://doi.org/10.12795/pixelbit.98768

Nunes, P. S., Nascimiento, M. M., Catarino, P., & Martins, P. (2020). Fatores que influenciam o uso de software educativo no ensino de matemática [Factors that influence the use of educational software in mathematics teaching]. *REICE. Revista Iberoamericana Sobre Calidad, Eficacia y Cambio En Educación*, *18* (3), 113-129. https://doi.org/10.15366/reice2020.18.3.006

Oliveira, A., Feyzi, R., Behnagh, Ni, L., Mohsinah, A., Burguess, K., & Guo, L. (2019). Emerging technologies as pedagogical tools for teaching and learning science: A literature review. *Human Behaviour and Emerging Technology*, *1* (2), 149-160. https://doi.org/10.1002/hbe2.141

Osborne, J. (2014). Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education*, *25* (2), 177-196. https://doi.org/10.1007/s10972-014-9384-1

Padilla, S. (2018). Usos y actitudes de los formadores de docentes ante las TIC. Entre lo recomendable y la realidad de las aulas [Teachers trainer's uses and attitudes before ICT. Between the advisible and the reality of classrooms]. *Apertura*, *10* (1), 132-148. https://doi.org/10.32870/ap.v10n1.1107

Paraskeva, F., Bouta, H., & Papagianni, A. (2008). Individual characteristics and computer self-efficacy in secondary education teachers to integrate technology in educational practice. *Computers* y *Education*, *50* (3), 1084-1091. https://doi.org/10.1016/j.compedu.2006.10.006

Plass, J. L., Milne, C., Homer, B. D., Schwartz, R. N., Hayward, E. O., Jordan, T., Verkuilen, J., Ng, F., Wang, Y., & Barrientos, J. (2012). Investigating the effectiveness of computer simulations for chemistry learning. *Journal of Research in Science Teaching*, *49* (3), 394-419. https://doi.org/10.1002/tea.21008

Pozuelo, J., Martín, J., Carrasquer, B., & Cascarosa, E. (2023). Percepciones del profesorado ante el uso de simuladores virtuales en el aula de ciencias [Teachers' perceptions about the use of virtual simulators in the science classroom]. *Revista Interuniversitaria de Formación del Profesorado. Continuación de la Antigua Revista de Escuelas Normales*, *98* (37.2). https://doi.org/10.47553/rifop.v98i37.2.95842

Rutten, N., Van Joolingen, W. R., & Van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers and Education*, *58* (1), 136-153. https://doi.org/10.1016/j.compedu.2011.07.017

Sahin, A., Top, N., & Delen, E. (2016). Teachers' first-year experience with chromebook laptops and their attitudes towards technology integration. *Technology, knowledge, and learning*, *21* (3), 361-378. https://doi.org/10.1007/s10758-016-9277-9

Shapka, J. D., & Ferrari, M. (2003). Computer-related attitudes and actions of teacher candidates. *Computers in Human Behavior, 19* (3), 319-334. https://doi.org/10.1016/S0747-5632(02)00059-6

Stieff, M. (2019). Improving learning outcomes in secondary chemistry with visualization-supported inquiry activities. *Journal of Chemical Education*, *96* (7), 1300-1307. https://doi.org/10.1021/acs.jchemed.9b00205

Tate, M., Evermann, J., & Gable, G. (2015). An integrated framework for theories of individual attitudes toward technology. *Information* y *Management*, *52* (6), 710-727. https://doi.org/10.1016/j.im.2015.06.005

Teo, T. (2008). Pre-service teachers' attitudes towards computer use: A Singapore survey. *Australasian Journal of Educational Technology*, *24* (4), 413-424. https://doi.org/10.14742/ajet.1201

Teo, T. (2012). Examining the intention to use technology among pre-service teachers: An integration of the technology acceptance model (TAM) and theory of planned behavior (TPB). *Interactive Learning Environments*, *20* (1), 3-18. https://doi.org/10.1080/10494821003714632

Teo, T., Milutinović, V., & Zhou, M. (2016). Modelling Serbian pre-service teachers' attitudes towards computer use: A SEM and MIMIC approach. *Computers* y *Education*, *94*, 77-88. https://doi.org/10.1016/j.compedu.2015.10.022

Trujillo, W., Curo, L., Paredes, L., & Carbajal, K. (2023). Eficiencia de los simuladores virtuales en la competencia de indagación para el aprendizaje de física elemental [Efficiency of virtual simulators in the inquiry competition for learning elementary physics]. *Telos: Revista de Estudios Interdisciplinarios en Ciencias Sociales*, *25* (2), 459-476.

Waight, N., Liu, X., Gregorius, R. M., Smith, E., & Park M. (2014) Teacher conceptions and approaches associated with an immersive instructional implementation of computer-based models and assessment in a secondary chemistry classroom. *International Journal of Science Education*, *36* (3), 467-505, https://doi.org/10.1080/09500693.2013.787506

Wen, C., Liu, C., Chang, H., Chang, C., Chang, M., Chiang, S. F., Yang, C., & Hwang, F. (2020). Students' guided inquiry with simulation and its relation to school science achievement and scientific literacy. *Computers* y *Education*, *149*. https://doi.org/10.1016/j.compedu.2020.103830

Wong, K. T., Teo, T. y Russo, S. (2012). Influence of gender and computer teaching efficacy on computer acceptance among Malaysian student teachers: An extended Technology Acceptance Model (TAM). *Australasian Journal of Educational Technology*, *28* (7), 1190-120. https://doi.org/10.14742/ajet.796

Wu, H. K., & Huang, Y. L. (2007). Ninth-grade student engagement in teacher-centered and student-centered technology-enhanced learning environments. *Science Education, 91*(5), 727-749. https://doi.org/10.1002/sce.20216

Xia, Y., & Yang, Y. (2019). RMSEA, CFI, and TLI in structural equation modeling with ordered categorical data: The story they tell depends on the estimation methods. *Behavior Research Method*, *51*, 409 - 428. https://doi.org/10.3758/s13428-018-1055-2

Zacharia, Z. (2003). Beliefs, attitudes, and intentions of science teachers regarding the educational use of computer simulations and inquiry-based experiments in physics. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *40* (8), 792-823. https://doi.org/10.1002/tea.10112

Authors' biographies

Alicia Palacios. Doctor of Biochemistry and Molecular Biology from the Universidad Complutense de Madrid. Accredited as an associate professor by ANECA. Academic Director of the Master's in Didactics of Physics and Chemistry at UNIR and professor of didactics of the experimental sciences in the Faculty of Education. Broad experience in the development of teaching innovation projects. Secondary education science teacher and editor for the publisher Edebé. Her research activity centres on the study of didactic resources and methodologies that foster active and contextualised learning in the sciences She is part of the "Didactics of Mathematics and the Experimental Sciences" (DIMACE) research group.

https://orcid.org/0000-0002-7906-1417

Rosa Gómez. Doctor of Research in Teaching and Learning of Experimental and Social Sciences and Mathematics from the Universidad de Extremadura. Professor and researcher in the Faculty of Education at the Universidad Internacional de La Rioja (UNIR) since 2017. Member of the "Didactics of Mathematics and the Experimental Sciences" (DIMACE) research group.

https://orcid.org/0000-0001-5861-9429

Álvaro Barreras. Doctor of Mathematics. Professor of mathematics (Centro Universitario de la Defensa de Zaragoza, 2014–2016). Professor of didactics of mathematics (UNIR, 2016–present). Academic director of two didactics of mathematics master's programmes. Lead researchers in the "Didactics of Mathematics and the Experimental Sciences" (DIMACE) research group at the UNIR.

https://orcid.org/0000-0001-5325-8505

Daniel Moreno-Mediavilla. Professor in the Faculty of Education of the Universidad Internacional de La Rioja (UNIR). Member of the "Didactics of Mathematics and the Experimental Sciences" (DIMACE) research group. Doctor of Chemistry from the Universidad de Burgos. More than 20 articles published in JCR and Scopus, and author of a patent.

https://orcid.org/0000-0002-5633-2376