Revista de Psicodidáctica 27 (2022) 186–193

Revista de Psicodidáctica

www.elsevier.es/psicod

Original

Adaptation of the direct and inferential mediation model of reading comprehension for Spanish speakers: A systematic review☆

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ARTICLE INFO

Article history:
Received 25 January 2022
Accepted 26 May 2022
Available online 9 June 2022

Keywords:
Reading comprehension
Prior knowledge
Decoding
Vocabulary
Comprehension strategies
Inferential ability

ABSTRACT

The direct and inferential mediation model proposes that reading comprehension is the result of relationships between prior knowledge, decoding, strategies, vocabulary, and inferential ability. The original model includes causal relationships, established when evidence of the direct effect of one of the components on another is found, and correlational relationships, proposed between some components when no causal evidence is found. The objective of this study is to adapt the model for Spanish speakers based on a systematic review. The causal relationships and the proposed correlations are supported by a single study or a meta-analysis, in both cases the effect size is significant. Causal relationships are also established when the effect size is not significant, but substantially important. Forty-three intervention studies are selected that support five causal relationships: from strategies, vocabulary and inferential ability to reading comprehension; and from prior knowledge and strategies to inferential ability. Seventy-four correlational studies that support seven correlations are also selected: between prior knowledge and reading comprehension; decoding and reading comprehension; strategies and prior knowledge; vocabulary and inferential ability; decoding and vocabulary; decoding and prior knowledge; and decoding and inferential ability. The effect sizes of the causal relationships are between $g = 0.47$ and $g = 1.16$, and the effect sizes of the correlations between $r = .2$ and $r = .47$.

Adaptación del modelo de comprensión lectora directo y de la mediación inferencial para hispanohablantes: una revisión sistemática

Palabras clave:
Comprensión lectora
Conocimientos previos
Descodificación
Vocabulario
Estrategias de comprensión
Habilidad inferencial

RESUMEN

El modelo directo y de la mediación inferencial propone que la comprensión lectora es el resultado de las relaciones entre los conocimientos previos, la descodificación, las estrategias, el vocabulario y la habilidad inferencial. El modelo original incluye relaciones causales, establecidas al encontrarse evidencias del efecto directo de uno de los componentes sobre otro, y correlacionales, propuestas entre algunos componentes al no encontrarse evidencias causales. El objetivo del presente estudio es adaptar el modelo para hispanohablantes a partir de una revisión sistemática. Las relaciones causales y las correlaciones propuestas están respaldadas por un solo estudio o un metaanálisis, en ambos casos, el tamaño del efecto es significativo. También se establecen relaciones causales cuando el tamaño del efecto es no significativo, pero sustancialmente importante. Se seleccionan 43 estudios de intervención que dan soporte a cinco relaciones causales: desde las estrategias, el vocabulario y la habilidad inferencial hasta la comprensión lectora; y desde los conocimientos previos y las estrategias hasta la habilidad inferencial. También se seleccionan 74 estudios correlacionales que dan soporte a siete correlaciones: entre los conocimientos previos y la comprensión lectora; la descodificación y la comprensión lectora; las estrategias y los

PII of original article:S1136-1034(22)00018-1.
☆ Please cite this article as: Martínez-Cubelos J, Salceda JCR. Adaptación del modelo de comprensión lectora directo y de la mediación inferencial para hispanohablantes: una revisión sistemática. Revista de Psicodidáctica. 2022;27:186–193. https://doi.org/10.1016/j.psicod.2022.05.001
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conocimientos previos; el vocabulario y la habilidad inferencial; la descodificación y el vocabulario; la descodificación y los conocimientos previos; y la descodificación y la habilidad inferencial. Los tamaños del efecto de las relaciones causales se sitúan entre $g = 0.47$ y $g = 1.16$, y los tamaños del efecto de las correlaciones entre $r = .2$ y $r = .47$.

Introduction

In Spanish speaking countries, there is concern about the low results in reading competence obtained in international studies (Mullis et al., 2017; OECD, 2019). Reading comprehension models can help organize a proposal for improvement in accordance with the progress of the research. The models can be classified into those that focus on explaining the cognitive and linguistic processes used to build the mental representation of the text and those that identify the components that predict reading comprehension. Among the former, the most relevant is construction-integration; although the landscape model, the structure building framework, the event-indexing model or the constructionist theory are also important (Butterfuss et al., 2020).

The component models make it possible to identify the knowledge and skills that need to be emphasized in order to improve reading comprehension. Normally, they can be easily applied in the educational field because they provide an explanation according to the perception that teachers have about reading competence. A model that has had a great impact is the simple view of reading. The original construction is based on a theoretical argument (Gough & Tunmer, 1986) that is later supported by the results obtained in a correlational study (Hoover & Gough, 1990).

The simple view of reading proposes that reading comprehension is the result of the interaction between two components that represent different processes: decoding and linguistic comprehension. Both components are of equal importance, since if either of them is compromised, reading comprehension will be affected. The influence of decoding and linguistic comprehension changes with age. During the first years of schooling, decoding contributes to a greater extent. This is because most cognitive resources are dedicated to phonological decoding and those dedicated to comprehension are residual. As readers begin to recognize words automatically, cognitive resources are released and, conversely, the contribution of linguistic comprehension is greater. The influence of the two components is also conditioned by the peculiarities of the different orthographies. In transparent ones, like Spanish, the contribution of decoding begins to lose weight before that in opaque orthographies like English. This is because high levels of reading accuracy are quickly reached because there is an almost unequivocal relationship between graphemes and phonemes (Florit & Cain, 2011; Gough et al., 1996; Ripoll et al., 2014).

The direct and inferential mediation model (DIME), although based on simple view of reading, is more complex, since in addition to decoding and linguistic comprehension (represented by vocabulary), it includes other components: prior knowledge, inferential ability and comprehension strategies. In addition, it not only proposes correlational relationships, as occurs in the simple view of reading, but also causal ones (Ahmed et al., 2016).

The DIME model represents an important field of research and offers some advantages over the simple view of reading. On the one hand, it proposes that after Primary Education the predictors of reading comprehension are the variables identified as relevant in the National Reading Panel report (2000), and others such as inferential ability. On the other hand, the relationships between its components are supported by an extensive literature review in which correlational, experimental and quasi-experimental studies are selected. However, it also has some disadvantages. It is a static model since it does not analyze how the contribution of the different components on reading comprehension changes according to age. The original conceptualization of the DIME model is proposed by Cromley and Azevedo (2007). The model is defined "direct" because all the components that constitute it directly influence reading comprehension and "inferential mediation" because most of the components, with the exception of decoding, influence reading comprehension indirectly through inferential ability. In the construction of the model, studies are selected in which students from fourth-grade or older participated. To establish causal relationships, it is marked as a criterion that at least one experimental or quasi-experimental study must show significant results. In cases in which it is not possible to establish a causal relationship based on this criterion, studies are sought to propose correlational relationships.

In the bibliographic review, 116 experimental and quasi-experimental studies were located, of which only three did not show significant results. From this set, ten causal relationships are proposed, although in two, the evidence is weak or contradictory: (a) prior knowledge to comprehension strategies: six studies with significant results and five with not significant results; (b) decoding to vocabulary: a single study with significant results. Seventy-three correlational studies are also selected that corroborate the proposed causal relationships and support three relationships for which no evidence from experimental or quasi-experimental studies is found. Correlational relationships are established between prior knowledge, vocabulary, and decoding.

To validate the model, data is collected from 177 ninth-grade students. Both prior knowledge and inferential ability are measured with questions related to the content of the texts in which reading comprehension is assessed. Inferences consist of establishing relationships between references and referents, discovering the meaning of expressions, identifying causal relationships that are not explicit, and making predictions based on events that appear in the text. Comprehension strategies are assessed as students' metacognitive awareness of the strategies. Vocabulary is measured as knowledge of words with similar meanings. Decoding is evaluated with measures of accuracy and rate in reading words and nonwords. Reading comprehension is assessed with literal and inferential questions after reading texts (Cromley & Azevedo, 2007).

The fit of four variations of the model, justified by causal relationships in which the evidence is weak or contradictory, is tested. Figure 1 shows in detail the model that best fits the data. Unidirectional paths represent causal relationships and bidirectional paths correlational relationships. In unidirectional paths, the component on which the intervention is carried out is located at the tail and the component on which the effect of that intervention is measured is located at the tip. The absence of unidirectional paths in the opposite direction or between decoding and inferential ability, decoding and comprehension strategies, and vocabulary and comprehension strategies indicates that no studies are located to support them.

The model assumes that prior knowledge directly influences reading comprehension when the text does not require the construction of inferences. Otherwise, their contribution is indirect through the inferential ability. In addition, when you have sufficient prior knowledge about the subject of a text; there are more possibilities to adequately implement comprehension strategies such as making predictions, detecting textual structures, detected

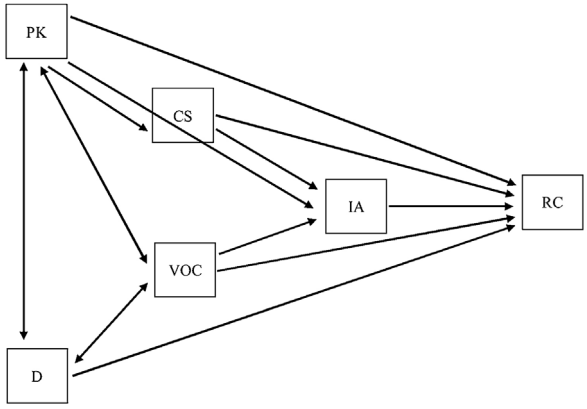

Figure 1. Graphic representation of the DIME model.
Note. D = decoding; PK = prior knowledge; VOC = vocabulary; CS = comprehension strategies; IA = inferential ability; RC = reading comprehension.

inconsistencies or making coherent summaries. The contribution of vocabulary is also direct; not knowing the meaning of a word compromises understanding, and indirectly through inferential ability; not knowing the synonym of a word prevents establishing a relationship between that word and its referent. In the same way, the influence of comprehension strategies is direct and indirect through inferential ability: making a good summary allows us to build inferences that during the reading of the text it has not been possible to make.

In a later study, Cromley et al. (2010) examine the validity of the original model in a sample of 737 undergraduates. The tests used to collect the data are related to the contents of the texts in which reading comprehension is measured. In the previous knowledge test and in the inference test, questions are answered after reading a text. Inferences consist of detecting relationships between references and referents, and drawing conclusions by relating prior knowledge and information from the text. Comprehension strategies are assessed with tasks such as summarizing, predicting, self-questioning, activating prior knowledge, taking notes, or integrating text and graphics. Vocabulary is measured as knowledge of the meaning of words. Decoding is evaluated with a "maze" format test. Reading comprehension is measured with literal and inferential questions. In order for the measures of vocabulary and prior knowledge to represent different constructs, a test of vocabulary breadth is used instead of depth. Its independence is verified through a confirmatory factor analysis. A new unidirectional path from vocabulary to comprehension strategies is added. Although no experimental or quasi-experimental studies are found, their presence is justified by assuming that in order to make a coherent summary it is necessary to know the meaning of the words in the text. The model that includes the new paths fits the data better than the original model.

The main objective of this study is to adapt the DIME model for Spanish speakers based on a systematic review. The reason is that adopting a model based on research carried out in another language can be risky, since the relationships between its components can be conditioned by the characteristics of the different orthographies. In irregular orthographies, such as English, decoding is more closely related to reading comprehension (Share, 2021). In addition, when reading unknown or highly irregular words, the syntactic cues of the text, vocabulary and prior knowledge are used to decode without making errors (Priebe et al., 2011). To achieve the objective of the research, the following questions are posed: (1) Which components of the original DIME model are unidirectionally related in Spanish speaking students? (2) Which components of the original DIME model are bidirectionally related in Spanish speaking students?

Method

Procedure to answer the research questions

To answer research question 1, intervention studies are selected in which evidence on causal relationships is provided, calculating their effect size. A meta-analysis is performed on paths that have at least two studies. To establish a unidirectional path, the relationship has to be supported by a meta-analysis or a single study, in both cases the effect size has to be significant or substantially important (0.25 or more standard deviations). The described process is used according to the indications of the version 4.0 of the procedures manual of the Institute of Education Sciences (2018a).

To answer research question 2, correlational studies are selected in which indices on the covariation between two or more components of the model are provided. Next, the primary effect sizes are obtained and a meta-analysis is performed on those paths that have at least two studies. To establish a bidirectional path, the relationship has to be supported by a meta-analysis or a single study, in both cases the effect size has to be significant.

Search strategy

The search is carried out between April 2019 and June 2020. It focuses on locating research published in scientific journals and grey literature. The electronic databases consulted are *Dialnet*; ERIC; *Iresie*; PsycINFO; *Recolecta*; *Redalyc*; *Redined*; *Repositorio Centroamericano*; *Repositorio Nacional del Gobierno de México*; *Repositorio Nacional Digital de Ciencia, Tecnología e Innovación*; *Red Iberoamericana de Innovación y Conocimiento Científico*; SCOPUS; *Sistema Nacional de Repositorios Digitales Teseo*; and Web of Science.

The search begins with the expression *"comprensión lectora"* or "reading comprehension", depending on the database consulted, no restrictions are used and all the located records are reviewed. However, when the records are difficult to manage, the search is limited to title; abstract; Social Sciences area; disciplines of Education, Psychology and Multidisciplinary; thematic areas of Psychology and Social Sciences; Spanish Language; or Spanish-speaking countries. Subsequently, combinations of Spanish the terms are used: *"comprensión lectora"* (reading comprehension), *"conocimientos previos"* (prior knowledge), *"estrategias de comprensión"* (comprehension strategies), *"metacomprensión"* (metacomprehension), *"metacognición"* (metacognition), *"inferencias"* (inferences), *"habilidad inferencial"* (inferential ability), *"comprensión inferencial"* (inferential comprehension), *"vocabulario"* (vocabulary), *"descodificación"* (decoding), *"fluidez"* (fluency) and *"reconocimiento de palabras"* (word recognition). For example, to perform a combined search for terms related to prior knowledge and decoding, use: *"conocimientos previos"* (prior knowledge) AND *"descodificación"* (decoding) OR *"fluidez"* (fluency) OR *"reconocimiento de palabras"* (word recognition). International databases use the English translation of these same terms.

In addition, a query is made requesting studies from 36 authors who have carried out research on reading in Spanish, receiving a response from 24. A reference search is also carried out in which the citations of previously known works are examined. That same strategy is used with the studies admitted after the selection of works.

Inclusion and exclusion criteria

The admitted studies meet the following criteria: (a) the participants are Spanish speaking students from fourth-grade or older;

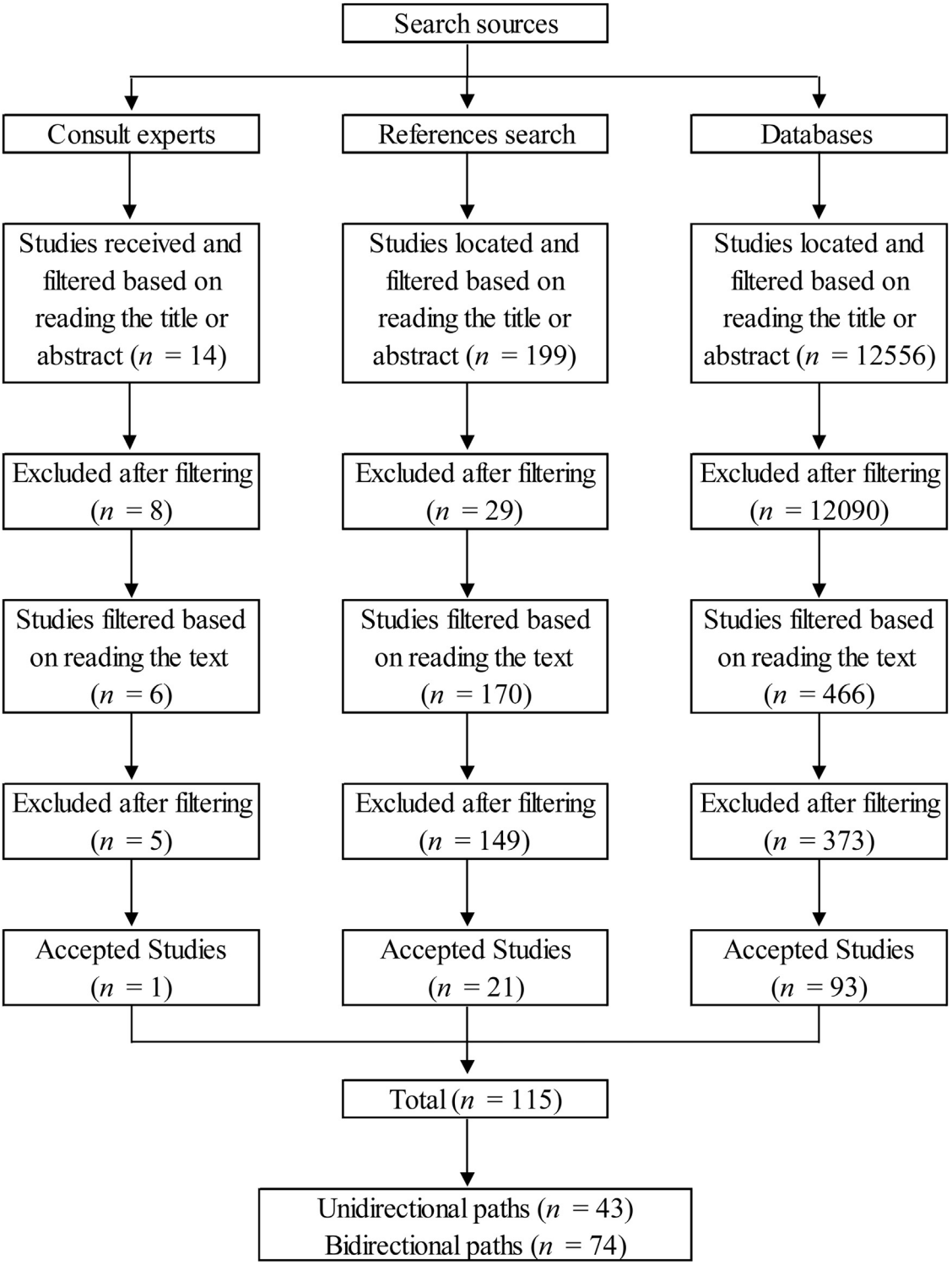

Figure 2. Flow-chart diagram.

(b) the sample has been constituted by selecting the available students or excluding those with neurodevelopmental disorders; c) the research design is correlational or it is an intervention with a control group, with an experimental or quasi-experimental design.

Admitted intervention studies also meet the following criteria: (a) the intervention focuses on a single component and its effect on other components of the model is assessed; (b) the participants are assigned to the experimental group and the control group randomly, and each one consists of at least 15 participants. When these conditions are not met, the groups meet the equivalence criteria proposed in version 4.0 of the standards manual of the Institute of Education Sciences (2018b) (Hedges' *g* less than or equal to 0.25 standard deviations); (c) the necessary data are provided to estimate the effect size according to the procedures manual of the Institute of Education Sciences (2018a).

In addition to those that do not meet the above criteria, studies with any of the following characteristics are excluded: (a) they do not include the segmented data of the courses of interest when

part of the sample is made up of students in courses less than fourth-grade; (b) they do not provide segmented data on students with typical development when students with neurodevelopmental disorders are also included in the sample; (c) the evaluations or interventions are carried out in a language other than Spanish; (d) between the evaluation before and after the intervention, a part of the sample is lost, which does not allow guaranteeing the prior equivalence of the groups.

To determine which studies are admitted, one of the authors of this article makes an initial selection based on reading the title or abstract to identify those potentially eligible. A final selection is then made from the text query. These studies are reviewed independently by two investigators and the reliability of selection is calculated using Cohen's Kappa. In intervention studies its value is .86 and in correlational studies it is .89. It is also independently reviewed which path each of the selected studies is included in. In unidirectional paths, Cohen's Kappa is 1, except: *Direct Effect of Strategies on Reading Comprehension* (.53) and *Direct Effect of Strategies on Inferential Ability* (0). In the bidirectional paths it is 1, except: *Correlation between Strategies and Inferential Ability* (.72), *Correlation between Vocabulary and Inferential Ability* (0), *Correlation between Inferential Ability and Reading Comprehension* (0), and *Correlation between Decoding and Vocabulary* (0). In cases in which Cohen's Kappa is less than 1, discrepancies are reviewed and resolved by mutual agreement. Figure 2 shows the study selection process.

The selected studies have been published in different media such as peer-reviewed journals (65.2%), doctoral theses (9.6%), master's dissertations (13.9%) and bachelor's thesis (11.3%).

Independence of effect sizes

Admitted studies cannot contribute multiple effect sizes to the same meta-analysis when they come from the same sample. This leads to errors in the estimation of variance and in the weight assigned to these effect sizes in the meta-analysis. In studies with multiple subgroups, such as grades or performance levels in the model components, the effects are entered into the meta-analysis as if they were different studies. On the other hand, when the measures to obtain the effect sizes are collected at different moments in time, with different evaluation tasks, there are several comparison groups or two studies share the same sample, it is understood that they are dependent and a measure is selected. randomly or based on pre-established criteria (Borenstein et al., 2009).

In studies that evaluate the same component at different moments in time, the first measure is taken into account. However, this is not done when for some reason it is considered necessary to select the measure that is collected in subsequent evaluations, for example, the evaluation instruments have better psychometric properties, the number of participants is higher or the necessary data are offered to give support more paths. In studies that use different tasks to evaluate the same component, the measurement made with the instrument with the best psychometric properties is chosen and, under equal conditions, the one most similar to the one used in the validation of the DIME model in English (Cromley & Azevedo, 2007; Cromley et al., 2010). If this criterion raises doubts for the reviewers, a random measure is selected. In intervention studies with multiple comparison groups, the experimental group that is equivalent to the control group before the intervention is selected. If several possibilities are found, the following criteria are taken into account. In studies in which the intervention focuses on the same component and the tasks are equivalent, the group in which the most extensive or complete work was done is chosen. When the tasks are different, the group in which they are most similar to those used to measure the component in the validation of the DIME model in English is selected (Cromley & Azevedo, 2007; Cromley et al., 2010). In studies in which the intervention focuses on different components, the group that can support the path with the least number of studies is selected. If several possibilities are found, one is selected at random. If any of the above criteria raise doubts for the reviewers, a group is selected at random. When the sample, or part of it, is shared in two studies, the one published in a peer-reviewed journal is chosen and, under equal conditions, the one that includes more participants or more reliable or complete data.

Coding procedure

Two code books are prepared in which the information of the selected studies is recorded, one corresponding to the unidirectional paths and the other to the bidirectional paths. An initial pilot is carried out to assess the reliability of the procedure in which two reviewers independently code a random sample of 20% of the admitted studies. The agreement between coders is measured with the intraclass correlation index for the quantitative variables. Because the reviewers code the same studies, intraclass correlation based on a two-way ANOVA with mixed effects is used. In the qualitative variables, agreement is measured with Cohen's Kappa. In cases where its value is less than .61, the discrepancies are resolved by mutual agreement, the coding criteria are reformulated and the variable is recoded. Subsequently, a new random sample of 20% is selected and the reviewers independently code the variables in which Cohen's Kappa is less than .61 in the initial pilot. The intraclass correlation values are between .817 and 1, and Cohen's Kappa is greater than .60 in all variables.

The information included in the code books consists of the type of publication (peer-reviewed journal, non-peer-reviewed journal, conference proceedings, doctoral thesis, master's dissertations, bachelor's thesis or chapter of the book); the country of origin of the participants; the selection of the sample (unselected or selection of participants with typical development); the size of the sample; the course of the participants; the type of evaluation instrument (standardized or non-standardized); the reliability and validity of the evaluation instrument; and the time at which the measurements are collected. The necessary data to obtain the primary effect sizes are also added.

Statistical analysis

In intervention studies, Hedges' g is calculated following the recommendations of the procedures manual of the Institute of Education Sciences (2018a) and in correlational studies, Pearson's r coefficient is used. Studies in which the coefficient of determination R^2 is provided are accepted when a component of the model is the only predictor or is introduced in the regression first, since in this case the value of R^2 is equal to the square of the Pearson's r coefficient ($R^2 = r^2$). Since it is found that the admitted studies differ in terms of evaluation instruments, the course of the students, the country, the research design and the characteristics of the interventions, a random effects meta-analysis is performed. The weight of the studies is calculated as the inverse of the sum of the intra-study and inter-study variance. The formulas proposed in the procedures manual of the Institute of Education Sciences (2018a) to estimate the pooled effect size, the confidence interval and the significance of the result of the meta-analysis, are loaded in Microsoft Excel. In the bidirectional paths, the r values, reported in the primary studies, are transformed to Fisher's Z before entering them in the meta-analysis and the results are returned to the original metric (Botella & Sánchez-Meca, 2015).

In the different meta-analyses, it is estimated whether the primary effect sizes share a common effect and the heterogeneity between them. In the first case, Cochran's Q statistic is used and in

the second, the I^2 index. In addition, publication bias is controlled with the Egger test in meta-analyses that have at least 10 studies (Botella & Sánchez-Meca, 2015). However, these results are not taken into account to make decisions in the adaptation of the model and are presented as complementary information.

Graphic representation of the model

When between two components of the model there is evidence to propose a unidirectional and a bidirectional path, the unidirectional path is represented. Unidirectional paths for which no evidence is found are replaced by bidirectional paths where possible. To represent the paths graphically, the value of the effect size, and the scope and level of evidence are taken into account. Single arrows are used on unidirectional paths and double arrow lines are used on bidirectional paths.

To symbolize the value of the effect size, lines are used from less to greater thickness according to the criteria of Cohen (1988). In unidirectional trails, these criteria are: small effect between 0.20 and 0.49, intermediate effect between 0.50 and 0.79, and large effect greater than 0.79. In the bidirectional paths they are: small effect between .1 and .29, intermediate effect between .3 and .5, and large effect .6 or greater. Solid and dashed lines are used to represent the level of evidence. The continuous lines correspond to the paths in which 50% or more of the weight in the meta-analysis comes from studies in which evaluation instruments are used that have at least one measure of reliability and another of validity. Dashed lines correspond to trails in which the weight is less than 50% or supported by a single study. Black lines are used in those trails in which the scope of the evidence is medium-large (350 or more participants) and gray lines when it is small (less than 350 participants).

Results

Participants

In the unidirectional paths, 48 independent samples made up of 3333 participants are admitted. Of these samples evaluated in the primary studies, in 42 samples the available students were selected, in four those with neurodevelopmental disorders were discarded, and in two they were chosen for their performance in some component of the model. The students who participate in the studies attend primary education (grades 1-6) (36.2%), grades 7-10 (36.1%), grades 11-12 (1.3%) and undergraduate studies (26.4%); and their countries of origin are Spain (43%), Peru (39.4%), Mexico (5.8%), Venezuela (4.1%), Colombia (3.6%), Chile (2.1%) and Bolivia (2%).

In the bidirectional paths, 84 independent samples made up of 18300 participants are accepted. Of those samples evaluated in the primary studies, in 64 samples the available students were chosen, in 17 those with neurodevelopmental disorders were discarded, and in three they were selected for their performance in some component of the model. The students who participate in the studies attend primary education (grades 1-6) (51.9%), grades 7-10 (20.1%), grades 11-12 (1.4%) and undergraduate studies (26.6%); and their countries of origin are Spain (52.6%), Uruguay (14.8%), Chile (11%), Peru (7.8%), Argentina (4.9%), Mexico (3.7%), Venezuela (2.4%), Dominican Republic (2.1%), Ecuador (0.5%) and Colombia (0.2%).

Instruments

In accepted studies, different ways are used to measure the same component. Previous knowledge is valued as domain-specific (91.3%), since it is related to the texts in which reading comprehension is evaluated, and as general knowledge (8.7%). Comprehension strategies are measured with questionnaires or scales of metacognitive strategies (64.7%) and with verbal reports or written tasks related to generating questions before reading, detecting textual structures, elaborating conceptual maps, detected inconsistencies or self-regulating comprehension (35.3%). Vocabulary is evaluated as comprehensive (60%) and mixed (40%). Inferential ability is assessed with inferences of the type (Ripoll, 2015): I (21.9%), II (40.7%), III (25%), IV (3.1%), V (3.1%), and unknown (6.2%). Decoding is measured as word reading rate (39.39%), word reading accuracy and rate (30.3%), word reading accuracy (9.1%), word and nonword reading accuracy and rate (6.06%), reading fluency (6.06%), word and nonword reading rate (3.03%), nonword reading rate (3.03%), and nonword reading accuracy (3.03%). Reading comprehension is evaluated as answering literal and inferential questions (76.92%), answering inferential questions (5.13%), answering literal questions (2.56%), summary (6%), cloze technique (5.13%), free recall (2.56%) and unknown (1.7%).

Alternative model proposal

The 43 admitted intervention studies provide evidence for eight unidirectional paths. Of those studies, four support several paths because the effect of the intervention is measured in more than one component of the model. A meta-analysis is performed in three paths and one is controlled for publication bias. The 74 selected correlational studies provide evidence for 14 bidirectional paths. Of these studies, 19 support several paths because the correlation between more than two model components is provided. A meta-analysis is performed in 12 paths and publication bias is controlled in 10. Figure 3 shows the graph of the adaptation of the DIME model for Spanish speakers. The paths are numbered to facilitate the exposition of the evidence found. The absence of a path between two components of the model indicates that no studies that meet the inclusion criteria are located or that the estimated effect size is not significant and, in the case of unidirectional paths, not substantially important either.

Although intervention studies are admitted in eight unidirectional paths, it is only possible to propose five, since in the rest the effects are not significant and not substantially important. The established unidirectional paths are three from comprehension strategies, vocabulary and inferential ability, to reading comprehension (paths 2, 4 and 5), and two from prior knowledge and comprehension strategies to inferential ability (paths 1 and 3). The effect size is between small and large, and the scope of the evidence is small, except for path 2, which is medium-large. Correlational studies are also found that provide additional evidence for unidirectional paths. In paths 6, 7 and 8 it is not possible to establish causal relationships, since, although intervention studies are admitted, the effects are not significant or substantially important. Evidences is found to propose seven bidirectional paths in which the effect size is between small and intermediate, and the scope of the evidence is medium-large. The characteristics of the meta-analyses can be consulted in detail in the supplementary material that accompanies this article.

Between comprehension strategies and vocabulary, it is not possible to establish causal or correlational relationships. Three independent samples from an intervention study and three from two correlational studies are admitted; but the pooled effect size is not significant, and in intervention studies it is not substantially important either. Similarly, no evidences are found to propose relationships between decoding and comprehension strategies, since a single sample from a correlational study is admitted, but the effect

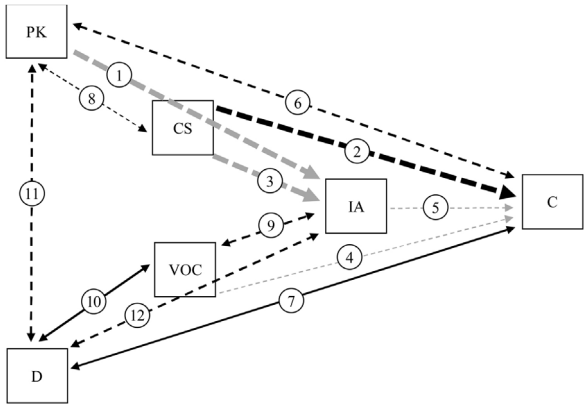

Figure 3. Graphic representation of the DIME model adapted for Spanish speakers. *Note.* D = decoding; PK = prior knowledge; VOC = vocabulary; CS = comprehension strategies; IA = inferential ability; RC = reading comprehension.

size is not significant. Table 1 shows the results of the statistical analyses in detail.

Discussion

In the adaptation of the model, five unidirectional and seven bidirectional paths are established. It has been found that there is a lack of research in Spanish in relation to English, since in the construction of the original model nine unidirectional and three bidirectional paths are proposed. In addition, 43 intervention studies are admitted in the adaptation and 65 in the construction of the original. No differences are observed in the correlational studies, since the number is similar, 74 in the adaptation and 73 in the original. Furthermore, the adaptation supports a bidirectional path for which no evidence is found in the original model, specifically, *Correlation between Decoding and Inferential Ability*. This relationship makes theoretical sense to the extent that once word reading is automated, more cognitive resources can be allocated to inference building. Given that it is based on the premise that there is a lack of research in Spanish, it is important to take into account some aspects related to the search for studies. In the construction of the original model, studies indexed in journals with peer review are accepted, two databases are reviewed and the search period is up to 2002. In the adaptation, the criteria are less restrictive. Research published in grey literature is also admitted, 15 databases are examined and the search term is until the year 2020.

Both in the construction of the original model and in the adaptation, the results are consistent for the unidirectional paths: *Direct Effect of Prior Knowledge on Inferential Ability*, *Direct Effect of Comprehension Strategies on Reading Comprehension*, *Direct Effect of Comprehension Strategies on Inferential Ability*, *Direct Effect of Vocabulary on Reading Comprehension*, and *Direct Effect of Inferential Ability on Reading Comprehension*. In the original model, all components have a direct and indirect effect, mediated by inferential ability, on reading comprehension. However, direct effects of prior knowledge and decoding, and indirect effects of vocabulary, are not found in adaptation.

In the adaptation process, studies are allowed on several paths proposed in the original model, specifically, between comprehension strategies and vocabulary and between comprehension strategies and decoding. However, no support is found because in the intervention studies the results are neither significant nor substantially important. In correlational studies, the results are not significant either. However, there is no reason to rule out these relationships, as the number of accepted studies is limited. Furthermore, these relationships can be justified theoretically. For example, to detect inconsistencies it is necessary to know the meaning of the words and when making a summary, automatic word recognition allows sufficient cognitive resources to be allocated to identify the important ideas of the text.

The adaptation of the DIME model must be taken into account with caution, mainly due to the low number of unidirectional paths. It should also be considered that in the paths *Direct Effect of Vocabulary on Reading Comprehension* and *Direct Effect of Inferential Ability on Reading Comprehension*, the effects are substantially important, but not significant. Furthermore, the extent of evidence on unidirectional paths is small, except for the *Direct Effect of Comprehension Strategies on Reading Comprehension*, which is

Table 1
Summary of results

Intervention studies									
PN	Path name	*N*	NS	NP	ES	*p*(ES)	Q	*p*(Q)	I^2
1	Direct Effect of PK on IA	1	1	37	0.97	< .05	–	–	–
2	Direct Effect of CS on C	38	41	2915	1.16	< .05	373.5	< .05	89.5
3	Direct Effect of CS on IA	1	1	46	0.99	< .05	–	–	–
4	Direct Effect of VOC sobre C	1	1	30	0.49	> .05	–	–	–
5	Direct Effect of IA on C	1	1	45	0.47	> .05	–	–	–
6	+ Direct Effect of CN on C	1	1	37	−0.61	> .05	–	–	–
7	+ Direct Effect of D on C	1	1	31	−0.07	> .05	–	–	–
8	+ Direct Effect of CS on PK	2	3	73	0.23	> .05	–	–	–
Correlational studies									
1	++ Correlation between PK and HI	8	12	1810	.42	< .05	43.46	< .05	74.7
2	++ Correlation between CS and C	29	30	5799	.39	< .05	392.3	< .05	92.3
3	++ Correlation between CS and IA	2	5	167	.21	< .05	4.5	> .05	12
4	++ Correlation between VOC and C	16	18	6563	.46	< .05	100.6	< .05	83.1
5	++ Correlation between IA and C	8	12	1340	.44	< .05	29.6	< .05	62.9
6	Correlation between CN and C	11	15	2396	.44	< .05	80	< .05	82.5
7	Correlation between D and C	24	28	6300	.36	< .05	60.2	< .05	55.1
8	Correlation between CS and PK	1	1	449	.2	< .05	–	–	–
9	Correlation between VOC and IA	4	5	357	.47	< .05	28.3	< .05	85.9
10	Correlation between D and VOC	7	7	1508	.33	< .05	100.9	< .05	94
11	Correlation between D and PK	6	8	1506	.36	< .05	12	> .05	41.6
12	Correlation between D and IA	9	11	1834	.31	< .05	38.5	< .05	74

Note. PN = path number, *N* = number of studies, NS = number of samples, NP = number of participants, ES = effect size, Q = heterogeneity statistic, I^2 = percent heterogeneity, D = decoding, PK = prior knowledge, VOC = vocabulary, CS = comprehension strategies, IA = inferential ability, RC = reading comprehension, *p*(ES) = <.05 significant effect size, *p*(Q) = <.05 studies do not share a common effect, + = since they were not significant or of a substantial size, they were represented as bidirectional paths as there was sufficient evidence from correlational studies, ++ = were included in the unidirectional paths because there was sufficient evidence from intervention studies.

medium-large. Another issue to keep in mind is that in the only path in which a meta-analysis is performed, the heterogeneity between the primary effect sizes is high (89.5%). In the bidirectional pathways in which a meta-analysis is performed, the heterogeneity is also high, obtaining values between 55.1% and 92.3%, except for the Correlation between Decoding and Prior Knowledge pathway, which is medium (41.6%). The high heterogeneity observed in some trials suggests that the results may be conditioned by moderating variables. These variables can be the age of the participants or the different ways of measuring the components.

The absence of the path *Direct Effect of Prior Knowledge on Reading Comprehension* can be justified by assuming that prior knowledge is not necessary in literal comprehension and that it only intervenes in reading comprehension indirectly (through inferential ability) when the text requires the construction of inferences. In this line, the construction-integration model proposes that readers with different levels of prior knowledge perform similarly in the construction of the base text (explicit information). However, in the integration phase the differences are important because the construction of the situation model requires putting in place the necessary inferential skills to be able to access the implicit information (Kim et al., 2021). However, in the only admitted study, reading comprehension is assessed as literal and inferential from a summary.

Considering the path *Direct Effect of Decoding on Reading Comprehension*, its absence can also be explained by the scarcity of research, since only one study is accepted in which accuracy and rate reading are worked. In transparent orthographies, rate reading should be stressed, since accuracy quickly loses weight, but rate continues to explain an important part of reading comprehension (Florit & Cain, 2011). Therefore, there are no compelling reasons to rule out a possible causal relationship. The absence of the *Direct Effect of Vocabulary on Inferential Ability* path can be explained by the lack of research, since no study was located. Another limitation of this review is the limited number of explicit instruments to measure inferential ability. In the 115 admitted studies, it is measured in 23 independent samples; but only nine use instruments that are not reading comprehension tests. These instruments consist of answering inferential questions after reading a paragraph or a text. In the remaining 14 samples, the inferential items of standardized reading comprehension instruments and instruments to measure rhetorical competence are used, that is, the ability to identify and interpret the mechanisms that give cohesion to the text (García et al., 2019).

Although the DIME model has been identified as relevant in research (Butterfuss et al., 2020; Duke & Cartwright, 2021), it has only been validated with grades 7 through 12 English language students (Ahmed et al., 2016; Cromley & Azevedo, 2007) and undergraduate studies (Cromley et al., 2010). Future studies are needed to assess its adjustment in Primary Education students and in orthographies with characteristics other than English. In addition, more research is required in Spanish to test the relationships for which no studies are located or the evidence is weak due to the limited number of admitted studies.

A practical implication of the DIME model is that it allows for more targeted assessments and interventions than the simple view of reading, since it incorporates more components. There are tools to assess the level achieved in these components, perhaps with the exception of the construction of inferences, for which there is no reference or commonly used test. On the other hand, ways to improve them have been described, which makes it a useful model for predicting comprehension difficulties, evaluating their causes and programming improvement actions.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.psicoe.2022.05.004.

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