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Designing Meta-analysis: Didactic Guidelines for Education Science Students

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Abstract: **In recent decades, meta-analysis has become an essential type of research in the field of educational sciences. This type of study synthesises published quantitative research on a specific topic. For this reason, this article offers a methodological protocol in which, from a didactic approach, we offer a series of recommendations and guidelines that could be useful to guide future researchers who are interested in this method of study. Through the explanation of the different phases involved in this process, we support ourselves on expert authors of this methodology and provide designs and support schemes that facilitate the performance of a meta-analysis of scientific rigour and quality. Finally, we also indicate a series of limitations and strengths inherent to the nature of this type of study.**

Keywords: **meta-analysis, methodological protocol, education, scientific literature.**

I. INTRODUCTION

In recent decades there has been a significant increase in the number of scientific publications (Dashper and Fletcher, 2019). Faced with this growth, the need for developing methodologies to compile and synthesise the main characteristics and contributions in any field of study arose (Sanchez-Meca, 2003). Consequently, systematic reviews were born in this context.

The term systematic review is used to refer to any effort to identify, select, synthesise, and analyse the most relevant studies around a research question (Martín, Tobías, & Seoane, 2006). These reviews are characterised by the use of clear and precise methods that analyse studies with a quantitative and qualitative orientation (Gough, Oliver, & Thomas, 2017). In addition, and in order to provide maximum scientific rigour, this methodology is characterised by a high level of systematisation (Grant & Booth, 2009). The aim of this nuance is to achieve a point of objectivity similar to any other scientific study (Sánchez-Meca & Ato, 1989; Sánchez-Meca & Botella, 2010; Botella & Zamora, 2017).

More than 13 different types of systematic reviews can be found in the scientific literature (Grant and Booth, 2009). Although each one contains distinctive nuances either in the search, analysis or synthesis processes, or in the objectives they address, they all share two fundamental aspects. On the one hand, in the absence of statistical or probabilistic analysis of their results (Sanchez-Meca and Botella, 2010). And, on the other hand, in the many criticisms associated with their subjective nature. These aspects led to the birth of meta-analysis as an alternative research methodology with the main objective of improving systematic review processes (Botella and Zamora, 2017).

Meta-analysis was born in 1976 thanks to Gene V. Glass, president of the popular American Educational Research Association (AERA) (Botella and Zamora, 2017). Since then, this methodology had the fundamental premise of bringing the analytical findings of research in the educational framework (Glass, 2016). The first meta-analyses were scientific literature reviews that summarised the results of studies with psychoeducational variables. However, after several decades, this methodology has spread into many other branches of knowledge, with medicine currently making the greatest efforts in this regard.

In general terms, meta-analysis can be defined as a type of systematic review that uses probabilistic and statistical methods to analyse the results of quantitative research (Litell et al, 2008; Botella and Sánchez-Meca, 2010; Pigott and Polanin, 2019). Therefore, a meta-analysis is part of a systematic review since it adds a quantitative analysis to the review, however, not every systematic review necessarily entails a meta-analysis (Sánchez-Meca and Botella, 2010). In this sense, authors such as Grant and Booth (2009) also state that a good prior systematic review is essential for the development of an optimal meta-analysis.

Other authors such as Cooper (2010) point out that the quantitative analysis process of a meta-analysis makes this methodology the most effective type of systematic review. In fact, at this time, meta-analysis has become an essential method for scientific work, as its application not only allows us to know and analyse the studies carried out until now, but also provides us information on possible biases in order to guide the future of research (Sánchez-Meca, 2003; Botella and Zamora, 2017; Pigott and Polanin 2019).

The main objective of a meta-analysis is to collect and bring the main findings of the quantitative research on a given topic (Piggot and Polanin, 2019). However, as mentioned above, this methodology not only involves data collection, but also requires probabilistic and statistical analysis processes that allow: 1) improving the relationship between the interventions and the outcomes of the selected studies; 2) determining the effect size of the research on a given topic; or even 3) studying the heterogeneity of the research analysed, among other aspects (Botella and Zamora, 2017). Therefore, we can summarise the main objective of a meta-analysis as: to gather, synthesise and analyse the effects of a given intervention on specific outcomes in a particular population. And all of this is based on a collection of quantitative empirical studies that attempt to answer the same research question.

Apart from this fundamental goal, Botella and Zamora (2017) also highlight other minor goals such as: 1) updating or improving previous meta-analyses by modifying inclusion/exclusion criteria or the selected databases and keywords; 2) or reformulating meta-analyses in order to include outcomes and effects not addressed in previous studies.

However, a prerequisite for meta-analysis is the existence of similar studies in terms of the intervention analysed, the effects produced, the measures considered and the characteristics of the sample (Grant and Booth, 2009). According to Saxon (1997), these requirements limit the methodological capacity of this methodology, as it is sometimes challenging to find enough similar studies on which to apply this method.

In addition to these aspects, Pigott and Planin (2019) highlight the need for transparency in meta-analytic processes. To this end, these authors emphasize the importance of explaining each of the decisions made in the research in so as to favour both, the validation of the results and the replication process by other researchers.

Despite the strong scientific support that this methodology enjoys due to its objective, precise and rigorous nature (Botella and Sánchez-Meca, 2015), the scientific literature highlights two fundamental problems associated with it: "heterogeneity", 'risk of bias' and "publication bias" (Banks et al., 2012; Pigott et al., 2013; Botella and Zamora, 2017). The first of these refers to obtaining unclear and generalisable conclusions when analysing studies with vastly different characteristics in terms of samples, methodology, measures, etc. (Grant and Booth, 2009; Marín, Sánchez-Meca and López, 2009). The other two consist of the editorial and scientific tendency to only accept those studies with statistically significant results (Torgerson, 2006). According to Palma and Delgado (2006), this poses a real danger to the validity of a meta-analysis.

Despite these problems, authors such as Botella and Zamora (2017) argue that none of them are caused by the methodology per se, but rather by extrinsic agents such as the ability of the researchers or by current editorial and scientific trends. In the latter sense, the meta-analysis also serves as an effective prevention tool.

The strong pressure to publish that has been observed in recent years has led to a significant increase in the amount of scientific research (Dashper and Fletcher, 2019). However, this increase has led to the development of unethical practices, a decline in research quality and even scientific fraud (Tudela and Aznar, 2013; Cannizzo, 2017; Beall, 2017, 2018; Overac, 2019). In this situation, meta-analysis serves as a scientific tool to identify the quality and effects that these practices generate in research (Botella and Zamora, 2017). In this way, this methodology will not only allow us to detect biases and future lines of research, but also areas, topics and studies treated in a superficial and cursory manner that need to be rethought (Sánchez-Meca, 2003; Botella and Sanchez-Meca, 2015; Botella and Zamora, 2017).

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In short, meta-analysis can be considered as an essential methodology for the advancement of science. For this reason and others, this article will provide a detailed guide for the development of an optimal meta-analysis. To this end, the phases and stages to be followed for the application of this methodology will be listed and described. In this sense, therefore, the phases to be considered would be: 1) formulation of the research problem; 2) search for studies; 3) coding of studies; 4) statistical analysis and interpretation; 5) publication. In each of the stages, the fundamental objective, the guidelines and ways of proceeding will be described. In addition, the main graphical tools to be used will be discussed in the fourth step. Finally, the article will conclude with some conclusions, highlighting both the limitations and the potentiality of this methodology.

II. STAGES OF A META-ANALYSIS

As explained in the previous section, a meta-analysis is a research method that has a number of similarities with other types of studies such as a systematic review of the literature. In fact, meta-analyses are often an analytical extension of a systematic review (Ahn & Kang, 2018). Throughout the process of developing a meta-analysis, we can see a series of phases that lead to a final product. However, it is important to highlight the flexible and multi-modal nature of this type of research (Field & Gillett, 2010). Thus, the phases presented below are indicative and may vary depending on the type of meta-analysis or its characteristics.

Phase 1. Formultion of the research problem.

This is the initial stage of our meta-analysis. In this sense, it is important to note that the research problem must be related to the association of two desirable study outcomes. The research question to be answered would be whether or not these outcomes are interconnected or linked. If this is the case, another interesting question would be to find out in what way this connection occurs (Glass and Smith, 1979). Furthermore, another of the main purposes to be considered in formulating the research problem is to estimate the treatment effect in a set of experimental studies (those that constitute our selected studies).

To make the process of constructing and specifying the research problem and research question easier, many authors recommend the use of the PICOS(T) framework (Martínez, Ortega and Muñoz, 2016; Schardt, et al., 2007). This process helps to specify each of the essential elements required for the research problem in a meta-analysis. In this sense, PICOS(T) is an acronym whose initials are explained and exemplified in table 1.

TABLE I: DESCRIPTION AND EXEMPLIFICATION OF THE COMPONENTS OF THE PICOS FORMAT

Acronym	Definition	Example	Potential research question
P	*Popullation*: Subject or group of subjects with certain characteristics that are of interest for the study.	Children aged 6 to 12 years	Does bilingual education improve the degree of intercultural sensitivity of primary school children (aged 6-12 years) compared to the control group with a traditional methodology?
I	*Intervention*: Intervention of interest that is applied to the subjects of analysis.	Bilingual Education	
C	*Comparaison*: Alternative intervention with which to compare the main intervention. Sometimes the second intervention may not exist (we would speak of PIO) or, even sometimes this second intervention is an absence of it.	Traditional education	
O	*Outcomes*: Effects generated on relevant dependent outcomes analysed in our study.	Intercultural sensitivity	
S	*Study Design*: Design of the studies to be included.	Quasi-experimental designs with control group.	
T	*Time:* Time or duration over which the research is carried out. This last aspect is optional depending on the characteristics of the study.	To assess the effect of the intervention (Bilingual Education) during a school year.	

Phase 2. Search for studies

This phase is fundamental to determining the quality of our meta-analysis (Cooper & Hedges, 1994). One of the main tasks to be carried out would be to locate and bring together relevant sources of literature to our object of study. This could be considered one of the most complex and demanding phases of the entire meta-analysis process, as it must meet certain criteria of systematicity and exhaustiveness so that those publications that are included truly meet the desirable characteristics of our study (Lipsey & Wilson, 2001). In this sense, the selection of keywords and the establishment of the search equations becomes a fundamental factor for the achievement of this purpose.

To this end, many authors recommend the use of the PICOS(T) format in order to contribute to the process of specifying keywords (Santos, Pimenta and Nobre, 2007; Landa-Ramírez and Arredondo-Pantaleón (2014),). In this sense, it is advisable to derive one or several keywords for each element of PICOS(T) framework.

On the other hand, several authors also emphasise the establishment of selection criteria (inclusion and exclusion) that allow a better identification of the scientific production in question (Erion, 2006). Some key points should be considered:

- In the literature search, use of precise terminology and databases to capture relevant publications.

- It is important to consider the interdisciplinary nature of the field of Educational Sciences to carry out broad searches. In other words, it would be advisable to establish exclusive terms from various disciplines that are linked to this area. For this purpose, it is recommended to use databases such as WoS, SCOPUS, Google Scholar, as well as some specialised educational databases such as ERIC.

- One aspect to consider, as we explained at the beginning, is the publication bias generated by the systematic nature of this type of research. For this reason, there is a tendency to consider only those studies that result from impact databases and are therefore published. However, there is unpublished or hardly accessible literature such as PhD theses, dissertations or expert reports that are unfortunately forgotten. These types of studies are commonly known as grey literature.

After this sequential search process, we enter the so-called "retrieval" sub-phase (Polanin, Pigott, Espelage & Grotpeter, 2019). Those publications of interest are selected, and we have to save the complete PDF. For this, the help of software that organises the entire body of documents is highly recommended. In addition, some meta-analysis experts explain that this process of sifting and retrieving publications for further analysis should be carried out by two or three researchers, and that, in addition, they should establish at least 2-4 meetings per month to discuss their progress.

Phase 3. Coding of studies.

In this phase, the main characteristics of the selected studies should be categorised and collected in tables. For this purpose, the use of Microsoft Word or Excel software is recommended for data collection. The characteristics that should be included are at least:

- Treatment outcomes

- Participant characteristics

- Sample size

- Research context characteristics

- Methodological characteristics

- Characteristics that are extrinsic to the scientific process, but which are essential when analysing the information.

Analysing these aspects becomes crucial in meta-analysis studies. In this way, the findings will allow us to obtain comprehensive clues about the influence of contexts, types of participants or methodology used in these publications. In addition, we can come closer to understanding the limitations of the external validity of this review (Wood & Eagly, 2009). On the other hand, this is also useful to examine how effect sizes vary across methods, contexts, and participants.

Another key point that brings quality to a meta-analysis is to provide a coding scheme of the studies. As explained above, categorising and coding the studies included in our meta-analysis is a costly process, in fact, some experts warn that it can take up more than 60% of the total review time (Pigott & Polanin, 2020). Nevertheless, good coding augurs a rigorous

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research process and with it, the likelihood of success. Therefore, thoroughness and precision are required to ensure the validity of Effect Size models. The question arises, what do researchers need to do to achieve this? Some of the following indications may be helpful:

- To construct a codebook that facilitates decisions on classification and inclusion of studies. This codebook should address the characteristics of the sample, intervention and control groups, outcome measurement, setting and methodological design as well as information on effect size. Figure 1 shows an example of a codebook from Botella and Gambara (2002).

STUDY	CHARACTERISTICS								RESULTS			
	SUBSTANTIVE			METHODOLOGICAL			EXTRINSIC		N_1	N_2	ES	p
	Type of treatment	Diagnostic	…	Design type	Control group	…	Year of public.	…				
1												
2												
3												
4												
5												
6												
…												
k												

Figure 1: Example codebook.

Source: Botella y Gambara (2002)

- Creation of a spreadsheet with all the complete entries in order to add the relevant data.

- A group leader who is in charge of designing a selection and classification criteria for the coding process is of great importance.

Finally, the research data should be entered into databases or softwares that will be used for the research. Some examples of software that can be used are *SPSS, Review Manager, Comprehensive Meta-analysis, Statistical Software for Meta-Analysis (MetaWin), Software for the Meta-analytic Review of Research Literature (DSTAT), ClinTools, The Meta-Analysis Calculator; Metastat, Metafor*, among a long list of others.

Phase 4. Statistical analysis and interpretation.

The main objectives of this phase are: 1) to find out the effect size caused by the independent outcome variable; 2) to study the degree of heterogeneity of the included studies; 3) to determine the existence or not of publication bias; 4) to investigate the relationship and the effect between the variables analysed; 5) to determine whether the overall effect is significant.

With regard to the overall effect (p), it is important to highlight that if the values are equal or greater to 0.05, there would not be a significant effect and we would be dealing with an intervention that does not cause substantial effects on the dependent outcomes under study (Cohen, 1994).

On the other hand, it is interesting to obtain the confidence interval (CI) and the pooled variance (σ^2). The confidence interval is a standard measure that calculates the effect size of each study from the data entered in the software, and also the overall effect size. It is selected through the analysis software itself and in most cases is usually predetermined as 95%. On the other hand, pooled estimation is used to estimate the variance between different types of populations when the mean of each population may be different, although in most cases it can be assumed that the variance of each population is the same.

The set of publications that make up our meta-analysis produces a given heterogeneity index (I^2) ranging from 0% to 100%. When the value is 0% exists homogeneity between studies. Values below 25% show homogeneity or trivial heterogeneity; between 25 and 50 % represents low heterogeneity; between 50 and 75 % mean medium heterogeneity; and between 75 and 100% would indicate high heterogeneity (Higgins and Green 2011).

When the heterogeneity is high, it is suggested to apply a random effect (RE) rather than a fixed effect (FE), since the random effect takes into account the possible differences between studies. However, a fixed effect does not take into consideration the different variables that may exist between studies (Sánchez-Meca, Martínez and Medina, 2006). After adding the type of effect, a sensitivity analysis should be performed in order to resolve heterogeneity. This consists of repeating the meta-analysis by exploring which of the included studies are responsible for the heterogeneity. If after this process, the heterogeneity values do not change considerably, we would have an example where the heterogeneity could not be resolved due to all (or the vast majority) of the studies would be different from each other. On the contrary, if the heterogeneity decreases significantly after the exclusion of certain study, the next step would be to analyse the reasons why this study causes inconsistencies between investigations. In this sense, the different aspects causing the heterogeneity (missing data, different characteristics, etc.) should be identified.

Before proceeding to the next stages of analysis and interpretation, it is relevant to discuss the magnitude of effect analysis of the standardised mean difference (MSMD) in depth. Thus, when we talk about this type of analysis, we refer to how much and/or in what way the desirable effect of the study is given. Table 2 helps us to interpret it in its multiple possibilities.

TABLE 2: EFFECT SIZE VALUES ACCORDING TO COHEN (1988)

Values	Values interpretation
< 0.20	Trivial effect.
≥0.20	Small effect size. No significant effect, no difference between groups.
≥0.5	Moderate or medium effect size.
≥0,80	Large effect size.

Source: Cohen (1988)

Another of the most common analyses in meta-analysis is the estimation of publication bias. This is commonly represented through the Light and Pillemer method (funnel plot) in which Egger's test is commonly used. This plot shows the effect (X-axis), size and precision (Y-axis) of the studies included in the meta-analysis. If a fixed effect has been applied, the plot would show the 95% confidence intervals (in form of a funnel), which assess the presence of heterogeneity of the meta-analysis dataset and estimates that 95% of the studies are within the lines of the funnel. In contrast, if a random effect is applied, the plot would not show the confidence intervals as it assumes that there is heterogeneity in the analysis. In addition, the funnel plot is composed of a vertical line showing the dispersion of the different studies through small dots (Borenstein et al. 2009). If the small dots (representing the publications included in the meta-analysis) are distributed in the side of experimental studies, it means that there are more studies showing that the independent outcomes have significant effects on the dependent outcome(s), and therefore could be indicative of a possible publication bias. This bias may be due to aspects such as funding, conflict of interest, publication language, desirability of significant results, institutional prestige, among others (Palma and Delgado, 2006).

On the contrary, if there is the same number of studies on the left as on the right, there is a less chance of publication bias due to a symmetric dispersion. Furthermore, if there is more predominance in the control group, there would also be a lower risk of publication bias as long as exists a symmetry in the effect size and precision of the investigations. Finally, it should be noted that the presence of heterogeneity (I^2) may cause asymmetry in the distribution of studies.

Phase 5. Publication.

After the set of analyses developed throughout the research process, the publication of these findings takes place in the form of a meta-analytical report. This report has different characteristics due to its methodological nature. In the following, we set out some guidelines that may be useful in the development of this report. To do so, we will base ourselves on the study by Botella and Gambara (2006), and offer a series of guidelines classified by sections:

- The term meta-analysis must appear in the title and abstract in order to identify what type of study it is. The subject matter of the study must be developed in a precise and concise manner. The abstract should indicate the number of publications included, the estimated standard error (SE) and the main findings.

- The introduction should include the reason why the meta-analysis is relevant, justifying it with high-impact scientific literature. In addition, a review of the current literature should be provided, and research questions should be posed that are consistent with the theoretical and empirical written aspects.

- The methodology section should be composed of sub-sections referring to the literature search, study selection criteria, coding of publication characteristics and statistical analysis. Thus, each sequential step followed throughout the research process should be reported in a detailed and exhaustive manner. In addition, the literature search should report the used databases, the established keywords and, furthermore, those procedures which detect scientific literature that has not been published. Another element of great rigour is to show the codebook used. In this section, another relevant point is to detail how the effect size has been quantified and whether a procedure has been established to improve the reliability of the coding process.

- With regard to the findings section, it is essential to provide tables and graphs showing the characteristics of the studies included in the review. In addition, it is recommended that the effect sizes obtained are summarised in descriptive or exploratory graphs. The aforementioned sensitivity analysis is an added value to our findings. Furthermore, it is appreciated that the effect size estimation and other complementary analyses are clearly presented. In addition, confidence intervals for the reported estimates are also provided.

- In terms of discussion, it is important to offer interpretations and literature linked to the obtained results. Furthermore, another point that complements this section is to indicate and suggest different future implications in the field of research and practice. The so-called "catch-all" is also an issue to be considered, and for this purpose it would be advisable to provide a list of possible threats that affect our findings.

III. CONCLUSION

Meta-analysis is a particularly useful form of research for quickly and synthetically analysing the scientific evidence on a specific topic. However, this type of study involves a complex and arduous methodological process. One of the main pieces of advice given by experts in this sequential work is to make decisions in a conscientious manner, and not because it is what is commonly done by others (Marín, Sanchez-Meca & Lopez, 2009). Furthermore, several researchers also mention that this process should be properly documented so that the reader may be able to replicate the same research with the provided data. Thus, transparency and replicability are key aspects throughout the writing of the meta-analytic report (Botella & Gambara, 2002).

Like all research, meta-analysis presents a series of limitations and potentialities, which have been explained in studies such as Walker, Hernandez & Kattan (2008) or Lee (2019), and are summarised in table 3.

TABLE 3: POTENTIALITIES AND LIMITATIONS OF META-ANALYSIS.

Potentialities	Limitations
- It synthesises information on a specific topic that will allow the researcher to bring together scientific evidence gathered over a period of time.	- Some studies do not adequately represent all the publications that cover a specific topic.
- It provides, through quantitative data, a numerical value for the evidence related to a specific topic.	- Focusing on English language alone leads to a systematic error in developing the search for potential studies.
- It elevates the findings to the first level of the pyramid of levels of scientific evidence.	- Questionable setting of selection criteria may bias potential results for our meta-analysis.
- It rediscovers new approaches and hypotheses that can be taken up in future studies.	- Regarding heterogeneity, if the studies included in the meta-analysis are too different, this could be a problem affecting the underlying findings.
- It can assess the extent of publication bias in a particular subject area.	- The quality of the included studies may compromise the validity of the results.
- This type of systematic review provides a higher degree of objectivity compared to other existing types.	- Because trials with statistically significant results are more likely to be published than those that are null, the conclusions of the meta-analysis may be biased.

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