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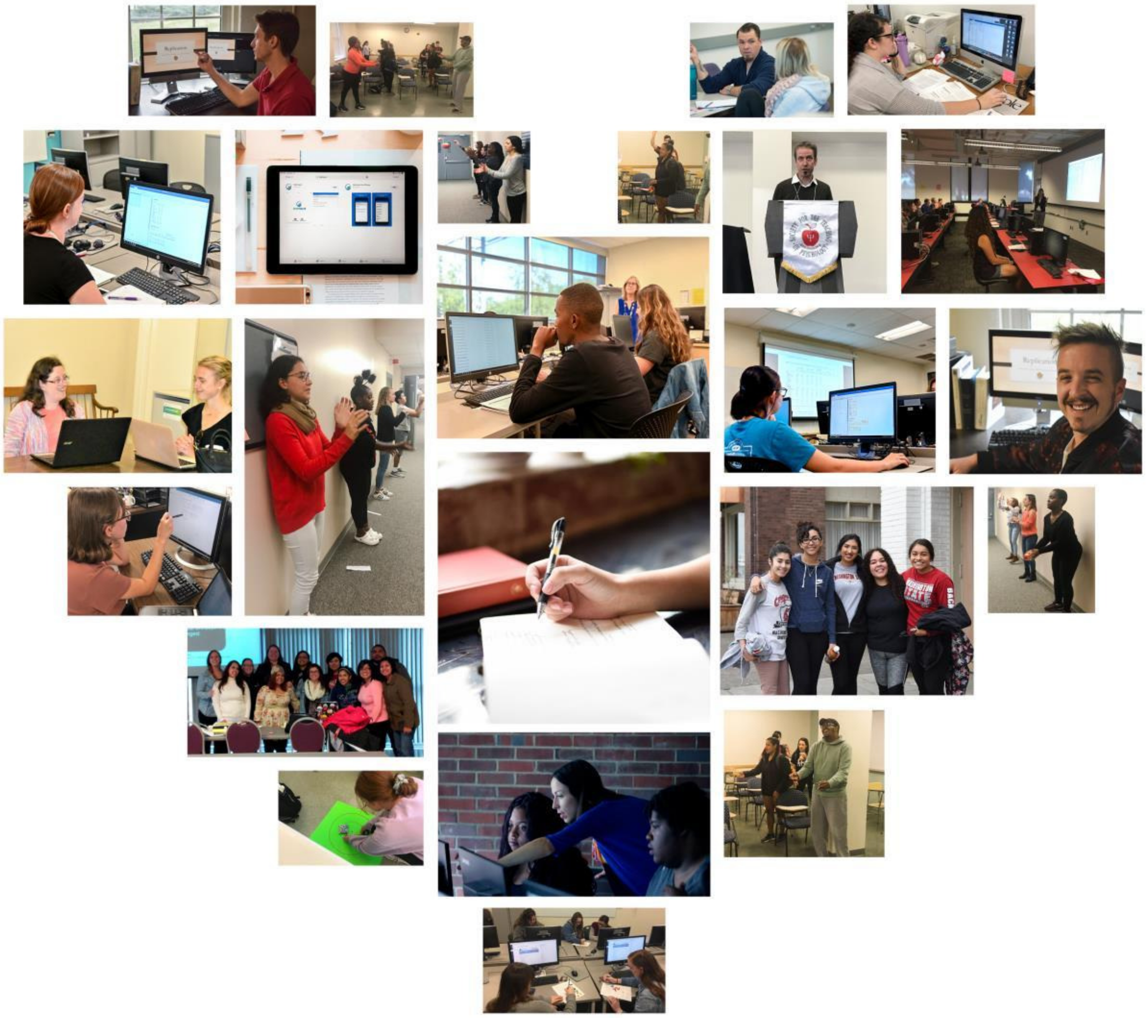
Meta-Analysis as a Tool for Increasing Students' Scientific Thinking

Jennifer Fayard



For the Love of Teaching

UNDERGRADUATE STATISTICS

Edited By:

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Summary

With the recent call for reforms in psychological science, researchers have advocated for practices like meta-analysis becoming more prevalent and taught as early as undergraduate statistics (e.g., Cumming, 2014; Funder et al., 2014). However, the vast majority of instructors do not teach meta-analysis at all (Friedrich, Childress, & Cheng, 2018) due to lack of time or unfamiliarity with the method. Instruction in meta-analysis can have many benefits for introductory statistics students, both practically and in terms of their larger understanding of science and statistics. Practically, meta-analysis integrates and reinforces concepts from statistics and research methods and help students consider what different types of research questions are answered with different statistical tests. On a larger scale, introducing meta-analysis in introductory statistics can help us train a new generation of students to think in terms of effect size rather than statistical significance, increase students' understanding of psychology as a science, encourage them to value replication, and help them take a broader view of research. The present chapter outlines several activities to introduce conceptual aspects of meta-analysis in the introductory statistics course that range from reading a meta-analysis and considering the results of conflicting studies to conducting a mini meta-analysis. It also includes resources for instructors to educate themselves about meta-analysis before presenting the material to students.

Introduction

Many professors are familiar with students who come into their first statistics course with a pronounced lack of interest (Rajecki, Appleby, Williams, Johnson, & Jeschke, 2005), or even an intense fear of math. Often, when statistics is paired with a research course, the context of using math to answer a question about human behavior helps them understand what those numbers mean, and if we are lucky, their fear turns to interest or even excitement. But is the reverse true—can understanding statistics help students understand how science works and how to do better research? Incorporating a meta-analysis unit in introductory statistics is an excellent way to reinforce basic concepts, provide a rich context for understanding how statistics and research design fit together, think critically about how to interpret statistics, and encourage students to value psychology as a science. In this chapter, I discuss the benefits and challenges of incorporating a meta-analysis unit in the undergraduate classroom and provide suggestions for activities and lectures, whether you have one day or one week to spend on the topic.

Meta-analysis is both a set of statistical techniques and a research method designed to estimate the overall strength of a relationship in the population by combining all of the existing data on that relationship in one analysis. Following the "replication crisis," concerns about publication bias, and criticisms of null hypothesis significance testing, the way we conduct and evaluate psychological science is changing, and meta-analysis is at the forefront of those changes. The field is moving toward greater emphasis on effect sizes over NHST, increased reporting of confidence intervals and statistical power, publishing interesting null findings, and focusing on cumulative methods such as replication and meta-analysis (Cumming, 2014; Eich, 2014; Stanley & Spence, 2014; Vazire, 2016;). In light of these changes, several researchers have highlighted the need for meta-analysis to be more widely taught at both the graduate and undergraduate level (e.g., Funder et al., 2014). However, according to a recent national surv y of psychology programs, most introductory statistics courses only cover effect size and confidence intervals for two days or less, and the overwhelming majority—between 73 and 84 percent—do not cover meta-analysis at all (Friedrich, Childress, & Cheng, 2018).

Why would we recommend that such an advanced technique be introduced at the undergraduate level? On a purely practical note, one reason we should introduce meta-analysis early on is that students will inevitably find meta-analyses in their literature searches. In my experience, most do not understand what they are, and thus discard them. But the benefits of this instruction go far beyond teaching students how to cite meta-analytic results. Besides training students in line with best practices in the field, a meta-analytic mindset prepares students to be better scientific thinkers by reframing their approach to research and data early in their academic careers. Below, I review a few of the specific ways meta-analytic instruction can benefit introductory statistics students.

Meta-Analysis Encourages Stronger Scientific Reasoning and Appreciation of Psychology as Science

Scientists build theories based on an accumulation of evidence rather than on the basis of a single study. Even if students understand this, they rarely have opportunities to watch scientists engage in this process. Further, despite content knowledge in psychology, many psychology majors do not develop a sense of psychology as science or understand the value of empirical studies (Holmes & Beins, 2009). There are several approaches to remedying this problem; specifically, meta-analysis not only offers an opportunity to emphasize the cumulative nature of our field, but also to explain why empirical studies are valuable, and provides an example of a concrete method in which scientists build on previous knowledge. In statistics and methodology courses, most examples center around a single study rather than asking students to make connections across multiple studies. This is not necessarily a bad thing, but we should take advantage of opportunities to show students how we practice our craft. This approach can help them understand how much weight to ascribe to single studies, as without this training, students often overemphasize the importance of a single study. We are all familiar with papers that rely on one article alone to serve as evidence for a phenomenon, sometimes even invoking the dreaded p-word (prove), despite our repeated insistence that they erase it from their vocabularies. Since meta-analysis considers an entire body of literature, it naturally emphasizes the need for replication before drawing conclusions. However, it can also challenge students' misconceptions and show them a more nuanced understanding of science in general and statistics specifically.

Meta-analysis encourages students to think in terms of the size and precision of an effect rather than a simple significant/not significant dichotomy (Cumming, 2014). When statistics courses focus on NHST, students often think of non-significant results as not meaningful. However, many real effects may not be statistically significant for one reason or another. In a meta-analysis, even studies that were not significant may contribute to a sizeable overall effect that has real-life consequences (Borenstein, Hedges, Higgins, & Rothstein, 2009; Braver, Thoemmes, & Rosenthal, 2014; Cumming, 2012). As with replication, a discussion of meta-analysis necessitates coverage of effect size and confidence intervals. Covering these topics in introductory statistics may help students think about effect size from the beginning and inoculate them against the all-or-nothing thinking associated with NHST.

Meta-Analysis Can Enrich and Integrate Statistical and Methodological Concepts

In addition to increasing scientific thinking, instruction in meta-analysis can help students understand the concepts they have learned in statistics more deeply. One way this can happen is through integrating statistics and research methods. There is evidence that taking statistics and research methods courses concurrently (Stranahan, 1995) or as integrated courses (Barron & Apple, 2014) increases student performance both immediately and long-term. Meta-analysis, by nature, forces researchers to think about statistics methodologically, so that even if they are not currently enrolled in a research methods course, they must consider which tests work with which methods and which tests are comparable. For example, if students find a correlational study and an experiment that uses a one-way ANOVA, they must think about whether the two statistics are answering the same fundamental research question and thus can be considered in the same analysis.

By requiring students to read and think about research, they see theory, research design, and statistics working together and gain practice reading, interpreting, and reporting statistics. Further, in meta-analysis, researchers must think critically about the statistics and methodology they encounter and make active decisions about how to handle it. This process can help students begin to gain confidence and a sense of agency in research and statistics and assist in their transition from novice to scholar.

Activities to incorporate meta-analysis concepts in the classroom

In an ideal world, every department would be able to offer an advanced statistics course that provides an in-depth coverage of topics like meta-analysis. Realistically however, you may have only one day in which to build an advanced topic into your introductory statistics course. I argue that even one day gives you an opportunity to introduce students to some of the principles associated with meta-analytic approaches and encourage them to begin thinking differently about data. Below I present some activities and materials that you can implement if you have one day or up to one week to spend covering meta-analysis. These activities are designed to be consistent with several APA and GAISE goals for teaching introductory statistics (Statistical Literacy Task Force, 2014; GAISE, 2016): focus on conceptual understanding (GAISE 2), distinguish between statistical significance and practical significance (APA 4), and teach statistical thinking (GAISE 1). In order to increase students' positive attitudes and self-efficacy for statistics and research methods and help them grasp the usefulness of meta-analysis, each activity is intended to be interactive, either in small groups or as larger class discussions, and provide a great deal of scaffolding (Ciarocco, Lewandowski, & Van Volkom, 2013). Further, each of these activities assumes that your course has already covered a few topics: caveats to null hypothesis significance testing, effect sizes, and how to read a journal article. Finally, especially if you have very limited time in your course, keep in mind that a discussion about meta-analysis will dovetail easily with an introduction to replication (Chapter 16), effect size, and confidence intervals (Chapter 17).

In addition to time constraints, one of the primary reasons statistics instructors do not cover meta-analysis is that they are not confident in their knowledge. If you are new to meta-analysis and would like to brush up before teaching it, a wonderful place to start is Cumming (2014). After that, Borenstein, Hedges, Higgins, and Rothstein's (2009) textbook provides brief chapters on various aspects of meta-analysis, and Cumming's (2012) text provides several user-friendly example exercises that pair with his (2016) ESCI Excel-based program, along with a step-by-step guide to conducting a larger-scale analysis. Chan & Arvey (2012) briefly review the advantages meta-analyses offer over single studies.

If you have only one day

With one day, you cannot teach a student how to perform a meta-analysis, but you can give them a conceptual understanding of how a meta-analysis works, ask students to think critically about familiar statistics in a real-life context, and present an example of ways meta-analysis can help scientists draw conclusions about behavioral phenomena.

Activity: Introduction to meta-analysis and making sense of conflicting data. It is an exciting moment when a student understands a results section they are reading for the first time, almost as if they have suddenly learned to speak a new language! However, it can be confusing or even upsetting for students when they first encounter inconsistent or conflicting results across different studies. For example, imagine that a student reads an article on power posing (Carney, Cuddy, & Yap, 2010) and implements posture changes in their daily lives, only to later read an article calling into question the validity of these studies (Ranehill, Dreber, Johannesson, Leiberg, Sul, & Weber, 2015). This raises many questions for them: Why did one study find statistically significant results while another did not? Which one should they believe? A student who has invested in the idea that standing up straighter will make them more confident and successful might simply ignore the conflicting findings and dismiss the failed replication attempt. However, for some, it might shake the foundation of what they have just learned in research methods and statistics. If all the experts don't agree, how will we ever find the true answer? Is all of our research just futile? In the worst case scenario, they may conclude that the field as not as scientific as we make it out to be! How can we equip students to grapple with inconsistency and uncertainty and prevent this scientific crisis of faith? The goal of this activity is to introduce meta-analysis as a tool for looking at the literature as a whole and showing students how to find trustworthy answers to their uncertainties and big questions.

The materials. You may choose any two articles for this activity, but I suggest a few in the appendix. These sets of articles were chosen for two reasons. First, both articles in each set have been included in a meta-analysis. I have referenced these meta-analyses so that, following the discussion about conflicting results and the introduction to meta-analysis, you can show students the meta-analytic effect of the relationship they read about in their homework. This activity could be done without an accompanying meta-analysis, but showing students the final result will make the activity more impactful. Second, the studies with null results were direct or conceptual replication studies, which may be helpful if you plan to blend instruction on meta-analysis and replication.

The homework. After students are familiar with a few types of basic statistics (e.g., Pearson correlations, t-tests, one- or two-way ANOVA), have students read two journal articles that show conflicting results and ask them summarize the main findings of both articles. Then, they should answer the following questions: What they would say if a relative read about this effect on the news and asked them, as a psychology major, if it was really true? Why do they think the studies found a discrepancy? Was one of them right and one of them wrong? What are the differences between the studies that might explain the difference in results? Depending on students' familiarity with research methodology, they may or may not be well-equipped to answer the latter question. If not, you may need to prompt them with questions asking them to compare the sample's demographics, materials and measures sections, and procedure sections and search for any differences they find. Students should bring a copy of both articles and their notes to class for the discussion.

The discussion. If you have a small class and the students are willing, it would be preferable to have a full class discussion. However, if you have a large or particularly shy class, you might break them up into groups of 4-5 students. When students arrive, ask them to talk about what they thought when they read the two articles. What conclusions, if any, did they walk away with about the variables in the study? As you guide them through discussing their homework questions, you may ask them to look at specific items such as differences in sample size between the two studies, as this may have contributed to statistical significance, and the effect sizes each article found regardless of statistical significance.

The lecture. After the discussion, instructors can introduce the basic goals and mechanics of a meta-analysis. There are a few important points to include. First, this type of analysis circumvents the issue of which of two conflicting studies to believe because meta-analyses examine all the existing studies on a relationship together to give an estimate of the true size of the effect in the population. Since one of the goals of theory building is to accumulate a great deal of evidence and replicate studies, meta-analysis is a more comprehensive and powerful way to examine the literature than looking at a collection of single studies individually. Second, meta-analysis emphasizes the magnitude of an effect and the precision with which we estimate it over statistical significance. Third, by attempting to find and include unpublished data, meta-analyses are less biased than single studies and traditional review articles. Finally, since many students are unsure how to interpret meta-analyses when they read them, brief instruction on how to read a meta-analysis would be useful.

If you have one week

With one week, you and your students can delve more deeply into the mechanics of a meta-analysis. The activity above is a great place to start introducing students to general concepts in meta-analysis, while the activities in this section get into mechanics and other issues. The first two activities below are designed to be done in one day, and either may be done in place of the activity on conflicting results if they would be better suited to your class.

Activity: Read and analyze a published meta-analysis. In order to give students a sense of what makes a meta-analysis different from and more powerful than a single study, students can read and analyze a published meta-analysis. In order to complete this activity, students should be familiar with the typical format for individual studies. Choose a meta-analysis and have students reflect on the method and results sections. In particular, have them note what elements make the analysis rigorous, detailed, and transparent. Ask them to compare the method sections of the meta-analysis and a traditional single study. What makes them different? Then, ask them to compare and contrast the results sections of a meta-analysis and a single study. What are the implications of both? Are the conclusions and certainty in the meta-analysis stronger than in the single study? If so, why?

In addition, students can evaluate the meta-analysis to see if it meets established guidelines for quality. There are a few systems for evaluating meta-analyses and systematic reviews, such as the Meta-Analysis Reporting Standards (MARS) in the 6^{th} edition of the APA manual, Cochrane Collaboration, and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The MARS and PRISMA systems are user-friendly to undergraduates and include a checklist for the minimum standards for reporting a meta-analysis (American Psychological Association, 2010; Moher et al., 2009). Students can review the criteria on the checklist and locate where the meta-analysis meets each.

Activity: Comparing meta-analyses and narrative reviews. Another useful exercise would be to have students compare a meta-analysis and a traditional narrative review article. An advantage of systematic reviews is that they examine the entire set of literature on a topic, and in the case of meta-analysis, offer a numeric summary effect. Because authors of narrative reviews choose which articles are important, do not typically justify why those particular articles were reviewed, and offer their own synthesis, they have a greater chance of being biased. Students may compare these two types of articles using a similar method as above, or you may even ask them to compare meta-analyses to single studies and narrative reviews simultaneously. Regardless of whether you choose articles that come to the same or different conclusions, you can still have a great discussion about the different methods they used to come to those conclusions, and which is most trustworthy and why. Article Set 2 in the Appendix gives examples of a narrative review and meta-analysis to compare.

Activity: Conduct a mini meta-analysis. The goal of this activity is to give students a taste of what is involved in actually conducting a meta-analysis. Students will have the opportunity to think critically about the literature and consider some of the questions scientists have to ask while performing this type of study. Dodd (2000) published a similar activity that could be used as an alternative to the activity below, but there are a few key differences between the two. Here, students will conduct their own literature search, establish and justify inclusion and exclusion criteria, organize and code their data, and analyze their data themselves. The present activity does not involve hand calculation or transformation, but if you wish, students may follow Dodd's (2000) procedure and convert effect sizes to Fisher's *z*.

The background: In order to successfully complete this activity, students should have had an overview of meta-analysis and experience with basic keyword searches in PsycINFO.

The setup: If you have two days or more to devote to this activity, you can very briefly take students through almost all the steps involved in conducting a meta-analysis! The ideal amount of time to complete this activity would be two full days, but it may be completed in less time with some modifications. Regardless of class size, this activity would work best in small groups of 3-4 students. In larger classes in which you cannot easily visit with every group, groups might do some work outside of class and bring their questions to class, email them, or post them on a discussion board.

The first step is to establish a research question. I recommend that the entire class decide on a topic together so that each small group is working on the same problem—managing one meta-analysis is challenging enough, and juggling students' questions about multiple topics would be quite cumbersome. Once you determine a relationship to study, each group should establish their own inclusion and exclusion criteria—which articles they want to use and which they want to exclude. One criterion that you may want to establish with all groups is type of effect size. Although meta-analysis software can transform multiple effect sizes into a single type, you may be unlikely to have the time or resources, and students may not have enough knowledge of comparable effect sizes, to do this. Thus, for ease of use, I recommend that you restrict studies to one type of effect size. Correlation is an excellent candidate, as it is straightforward to understand, requires no additional transformation, and is compatible with the free software I reference below. However, this would be a good time to ask students to think about what types of research questions different statistics answer. Should correlations, t-tests, and ANOVA go in the same meta-analysis? Why or why not? Aside from effect size, in order to practice transparency and encourage students to think actively about the decisions they are making, students should attempt to explain why they chose an exclusion criterion, particularly if they exclude studies based on demographic characteristics, sample size, quality of the study, measures, operational definition, or another methodological element.

Next, walk students through setting up their database. In Excel or another spreadsheet program, students should have columns for study name (authors, year), sample size, correlation, measures used, and sample characteristics (e.g., undergraduate students, community sample, members of an online cat forum). They should also keep lists of keywords and combinations of keywords they search and notes on articles they strike from the analysis based on their exclusion criteria.

The literature search. Each group should aim to find five articles that meet their inclusion and exclusion criteria. I strongly recommend doing a preliminary search to assess how difficult it is likely to be to find appropriate articles—some topics will be easier than others. One way to considerably shorten the time required would be to provide a set of articles for students to review rather than have them conduct their own search. This might be especially helpful if your students have not had much experience searching for articles. If you do this, I recommend giving them some articles that are likely to be excluded based on their criteria so that students get the experience of justifying rejecting an article.

The analysis: Once your groups have found five articles, you may analyze the meta-analytic effect. There are two free options for running a basic meta-analysis. The easiest to use is Cumming's (2016) ESCI software, especially if you are unfamiliar with R (but see Chapter 18 if you are interested in learning more about R). This program runs in Excel and gives a summary effect, confidence interval, and forest plot for up to 30 studies. Kovalchik (2013) published a thorough guide to conducting meta-analysis in R that includes examples and a comparison of the features and graphics from three different R packages. These packages also present basic output and forest plots. Students should examine the basic statistics and discuss how to interpret the magnitude of the effect size and the width of the confidence interval. Due to the nature of this exercise, it would not be very informative to conduct a publication bias analysis. However, you may demonstrate changes in the effect by adding or removing studies to simulate including or excluding unpublished data (see Cumming, 2012 for an example in ESCI).

Activity: Apply a meta-analysis. In order to demonstrate the utility of meta-analysis, you may ask students to use the results of a meta-analysis to develop and justify a policy recommendation. This policy may be at the organizational level, such as a club; at the institutional level, such as your university; or at the national level. In their justification, students can explain what meta-analysis is, what it tells us, and why meta-analytic findings are strong enough to warrant a recommendation for action. Alternatively, to emphasize meta-analysis's role in theory building, students might use the results to design a new study on that topic.

Outcomes: A New Generation of Scholars?

I developed these activities for introductory statistics and research methods based on my experiences teaching a full-semester undergraduate course on meta-analysis. All the activities except the Mini Meta-Analysis and Apply a Meta-Analysis are the same or a variation on activities students complete early in the full course to get the lay of the land before diving into a full meta-analysis. I have had the opportunity to teach the course twice, and both times I have seen a dramatic change in my students' understanding of and attitude toward research and statistics, as well as an increase in their level of scientific thinking. They transformed from passive recipients of facts to active, creative scholars. They increased in their self-confidence about statistics, which has increased their excitement about research. In feedback, students have reported that they have a greater understanding of psychology as a science and that the "bird's eye view" of the field they saw helped bring together ideas they encountered across the psychology curriculum. While a shorter period of time may not yield such pronounced changes, these activities may plant the seeds for more growth as they advance in their coursework.

Advice and Conclusions

Students have a lot to gain from even a brief unit on meta-analysis. However, these are challenging concepts to teach. In my experience, it is best to plan to go slow and be prepared to go even slower. It is easy to be ambitious when teaching meta-analysis, but students must have a good grasp of the prerequisite material before they can grapple with the more advanced concepts. But if you are patient, encouraging, and meet them at their ability level, most of them will rise to the challenge. Of course, meta-analysis is not perfect, and it is not immune from bias (Borenstein, Hedges, Higgins, & Rothstein, 2009; Chan & Arvey, 2012), but it is a valuable tool and has the potential to change students' perspectives. After this unit, I hope you will be rewarded with students who are interested in how science works and who, regardless of whether they go on to graduate school, will be better equipped to evaluate scientific data.

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Appendix: Articles to Use in Activities

Set #1: Does Ego Depletion Lead to Self-Regulation Failure?

Significant effect: Food consumption

- Oaten, M., Williams, K.D., Jones, A., & Zadro, L. (2008). The effects of ostracism on self–regulation in the socially anxious. *Journal of Social and Clinical Psychology, 27*, 471-504.

Null effect: Food consumption

- Dingemans, A.E., Martijn, C., Jansen, A.T.M., & van Furth, E.F. (2009). The effect of suppressing negative emotions on eating behavior in binge eating disorder. *Appetite, 52*, 51-57.

➢ Note: Two meta-analyses have been published on ego depletion, one that did not include unpublished data (Hagger et al., 2010) and one that did (Carter et al., 2015), and the papers came to different conclusions about whether ego depletion is a real phenomenon. If you wish, you could use these analyses to demonstrate the impact of publication bias.

Meta-analysis 1:

- Carter, E.C., Kofler, L.M., Forster, D.E., & McCullough, M.E. (2015). A series of meta-analytic tests of the depletion effect: Self-control does not seem to rely on a limited resource. *Journal of Experimental Psychology: General, 144*, 796-815.

Meta-analysis 2:

- Hagger, M.S., Wood, C., Stiff, C., & Chatzisarantis, N.L.D. (2010). Ego depletion and the strength model of self-control: A meta-analysis. *Psychological Bulletin, 136*, 495-525.

Set #2: Does Consuming Sugar Restore Self-Regulation Capacity Following Ego Depletion?

Significant effect:

- Gailliot, M. T., Baumeister, R. F., DeWall, C. N., Maner, J. K., Plant, E. A., Tice, D. M., . . . Schmeichel, B. J. (2007). Self-control relies on glucose as a limited energy source: Willpower is more than a metaphor. *Journal of Personality and Social Psychology, 92*, 325-336.

Null effect:

- Lange, F., & Eggert, F. (2014). Sweet delusion. Glucose drinks fail to counteract ego depletion. *Appetite, 75*, 54-63.

➢ Note: Here, we have a narrative review (Galliot & Baumeister, 2007) and a meta-analysis (Dang, 2016) that come to different conclusions. These articles may be useful for comparing narrative reviews to meta-analyses.

Narrative review:

- Galliot, M.T., & Baumeister, R.F. (2007). The physiology of willpower: Linking blood glucose to self-control. *Personality and Social Psychology Review, 11*, 303-327.

Meta-analysis:

- Dang, J. (2016). Testing the role of glucose in self-control: A meta-analysis. *Appetite, 107*, 222-230.

Set #3: Does Ovulation Affect Women's Mate Preferences?

Significant effect:

- Durante, K.M., Griskevicius, V., Simpson, J.A., Cantú, S.M., & Li, N.P. (2012). Ovulation leads women to perceive sexy cads as good dads. *Journal of Personality and Social Psychology, 103*, 292-305.

Null effect:

- Peters, M., Simmons, L.W., & Rhodes, G. (2009). Preferences across the menstrual cycle for masculinity and symmetry in photographs of male faces and bodies. *PLoS ONE 4(1)*: e4138.

Note: Two meta-analyses on this relationship were published the same year and found different results. If you have time, you might examine the differences between these meta-analyses with students and ask them to think about why two meta-analyses might have reached two different conclusions.

Meta-analysis 1:

- Gildersleeve, K., Haselton, M.G., & Fales, M.R. (2014). Do women's mate preferences change across the ovulatory cycle? A meta-analytic review. *Psychological Bulletin, 140*, 1205-1259.

Meta-analysis 2:

- Wood, W., Kressel, L., Joshi, P.D., & Louie, B. (2014). Meta-analysis of menstrual cycle effects on women's mate preferences. *Emotion Review, 6*, 229-249.