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# Efficacy of Professional Development Models in Dismantling Scientific Misconceptions

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EFFICACY OF PROFESSIONAL DEVELOPMENT MODELS IN DISMANTLING SCIENTIFIC MISCONCEPTIONS

by

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# ABSTRACT

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by

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Teachers addressing scientific misconceptions in the classroom is paramount to student learning, as identifying and deconstructing misconceptions is an important part of shaping a student's conceptual framework. However, teachers harbor misconceptions themselves and are ill equipped to adequately identify or mediate them. Thus, there is a need for effective professional development to address misconceptions. While there have been studies conducted on such professional developments, there is a dearth in the literature as to what makes these professional developments successful in combating misconceptions. Consequently, it is important to understand what constitutes efficacious methods of professional development regarding misconceptions. Therefore, the purpose of this study is to investigate which models of professional development are most effective in correcting misconceptions commonly held by teachers to improve their instruction. I investigated this via meta-analysis and meta-synthesis of existing studies that have utilized professional development as a means of overcoming misconceptions. Since elementary and secondary teachers have been well documented to harbor misconceptions, I included both in my investigation. Success of professional developments were measured in this study by pre and post test scores from selected studies and by determining overall themes from the literature. Research on the topic of teacher misconceptions suggest some form of professional development, but do not specify which models of professional development are the most effective. After an initial collection of data, studies were categorized as more pedagogically focused or more content focused. Additionally, data was categorized as professional developments being offered to elementary or secondary teachers. The results indicate no significant differences between pedagogically focused or content focused professional developments. Additionally, there were no significant differences between elementary and secondary professional developments and their efficacy. The implications of this study are that a pedagogical content knowledge approach may be promising for professional developments in the future, secondary teachers benefit from professional developments regarding misconceptions, despite their greater science training, and that elementary school teachers should be offered more content heavy professional developments.

(50 pages)

# PUBLIC ABSTRACT

## EFFICACY OF PROFESSIONAL DEVELOPMENT MODELS IN DISMANTLING SCIENTIFIC MISCONCEPTIONS

Tyler Hansen

Scientific misconceptions held by educators are both common and well documented. As science education becomes more and more important to students, it is evident that there is a need to not only identify scientific misconceptions held by teachers as a means of bettering the education of students, but also determine effective methods of deconstructing them. Although studies have indicated that professional development can assuage the prevalence of misconceptions held by teachers, there is a dearth in the literature of what makes these professional developments effective. Therefore, this study investigated which models of professional development are most effective in dismantling misconceptions commonly held by teachers. To do this, I collected both qualitative and quantitative data from existing papers regarding misconceptions and professional development. I found that both elementary and secondary teachers benefit in terms of bettering their understanding of misconceptions from both learning science content and learning about teaching in equal amounts. This is surprising because it means that secondary science teachers also need more content training, despite having much more science training than elementary school teachers have. Therefore, the implications of this study are that secondary and elementary school teachers need to be offered more content focused professional developments in order to address their own misconceptions and address misconceptions in their classrooms.

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# CHAPTER 1 INTRODUCTION

## Statement of the problem

Across the literature, a wide range of terms are used to discuss scientific misunderstanding. Sometimes called misconceptions, personal conceptions, or private conceptions, these misunderstandings can range from minute to extensive. For the purposes of this study the term misconception is used to refer to any understanding of science held by an individual that contradicts current scientific knowledge and understanding. However, this definition is not meant to convey ideas about a deficit of knowledge in an individual that holds a misconception. Rather, a misconception refers to existing ideas that individuals develop in order to make sense of the world around them (Smith et al., 1997). Additionally, misconceptions should not be thought of in isolation. They exist within - and inform - a larger framework of understanding for that individual.

Teachers addressing misconceptions in the classroom is important, as recognizing and deconstructing them will lead to purposeful instruction and greatly assist in molding students' existing conceptual knowledge. For example, Larkin (2012) states that misconceptions can be used as "the raw material of classroom learning, student ideas may be refined, revised, bridged, and built upon by both teachers and students alike." (pg. 932). Student misconceptions should not be thought of as primitive ideas in desperate need of correction here, but rather pedagogical tools for science education. That said, in order to utilize misconceptions as an instructional practice, teachers need to become aware of their own misconceptions and how to appropriately address student misconceptions. There is a need for professional development for teachers which educates them on misconceptions. Despite this well documented and pressing issue, little improvement has been accomplished by professional development or teacher training at a large scale. Burgoon et al. (2011) found that, even after 30 years of research, elementary school teachers still retain misconceptions similar to that of their students. Additionally, even teachers that understand student misconceptions may not view discussing them as a priority (Moodley & Gaigher, 2019).

This study focuses on analyzing professional developments used regarding scientific misconceptions in order to determine effective methods for misconception education. From the literature reviewed, many studies that involve teacher misconceptions recommend some form of professional training (Ilyas & Saeed, 2018; Widiyatmoko & Shimizu, 2018; Rasul et al., 2019; Moodley & Gaigher, 2019). Professional developments are imperative for science education reform (Desimone, 2009). Professional developments for science educators obviously vary greatly in their methods and desired outcomes. However, most professional developments for science teachers focus on increasing knowledge in both content and pedagogy in order to ultimately improve student learning (Moyer-Packenham et al., 2011).

**Difficulty with Misconceptions**

Teachers find difficulty in teaching about misconceptions for a myriad of reasons. First, teachers have been documented to harbor misconceptions themselves (Burgoon et al., 2011). If teachers have the same misconceptions as their students then correctly identifying them is an obvious impossibility. Second, many teachers do not seem to understand what misconceptions are. Gomez-Zwiep (2008) found that teachers had difficulty defining the term misconception and recalling common misconceptions that they had heard in the classroom. Misconceptions are not a deficit in student understanding and defining them as such inherently ignores the potential of using a student's existing knowledge for instructional planning. This is further evidenced by Moodley & Gaigher (2019), who found that even teachers that could identify common misconceptions did not know how to adequately address them. Consequently, teachers need more training in not only content, but pedagogy as well.

**Professional Development on Misconceptions**

Studies regarding misconceptions typically recommend professional development to mitigate both teacher misconceptions and to improve their pedagogical content knowledge (Akerson et al., 2000; Burgoon et al., 2011; Fulmer, 2013; Gomez-Zwiep, 2008; Kikas, 2004; Morrison & Lederman, 2003; Appleton, 2003; Atasoy et al., 2011; Rasul et al., 2019; Hill et al., 2008; Moodley & Gaigher, 2019). Similarly, as our science standards have now oriented themselves towards science and engineering practices (NRC, 2012), professional developments have also shifted towards providing teachers with the pedagogical content knowledge needed to implement these new standards (Kuehnert et al., 2019). Pedagogical content knowledge is defined as understanding specific content well enough to implement effective pedagogical practices (Shulman, 1986). Understanding science alone is insufficient for this framework, as teachers must also understand how students learn science. Understanding misconceptions is therefore an important aspect of pedagogical content knowledge (Shulman, 1986). Consequently, research on the efficacy of professional developments have utilized a teacher's understanding of student misconceptions as a measurement for pedagogical content knowledge (Doyle et al., 2018; Kuehnert et al., 2019; Park et al., 2010).

While the measurements of success of professional developments varies greatly (Doyle et al., 2018), there have been several studies that indicate professional developments have a positive impact on mitigating misconceptions. For example, Rasul et al. (2019) implemented a constructivist teacher training model in order to mitigate misconceptions regarding heat and found a significant decrease in the number of misconceptions pre-service teachers held.

Furthermore, Rozenszajn & Yarden (2013) explored the effects of a two-year professional development program on three biology teachers' pedagogical content knowledge and found that these teachers benefited from the misconceptions portion of the course. Finally, Kuehnert et al. (2019) conducted a meta-analysis on reform-based STEM professional developments and found significant increases in pedagogical content knowledge for both in-service and pre-service teachers in both math and science. These increases were measured via multiple-choice assessments that targeted student work and misconceptions, implying that teachers improved their ability to identify and address misconceptions.

Although the studies indicate promising results of professional developments, research regarding the efficacy of professional developments in general is obscured by a multitude of factors. Most research on professional developments is highly targeted, making sample sizes small and outcomes difficult to compare (Doyle et al., 2018). One of the few large-scale studies, TNTP (2015), found no differences between professional development and teacher improvement. This study used a variety of metrics in determining teacher improvement, although they did not use knowledge on student misconceptions as one of them, across three large school districts. However, the most pertinent study that raises questions about the efficacy of professional development is Doyle et al. (2018). This large-scale study investigated professional development features and their effects on teachers' knowledge of student misconceptions. They found that professional developments overall did not improve teachers' understanding of misconceptions. When comparing professional developments that include designing curriculum and assessment tools to teachers' understanding of student misconceptions, there was actually a negative correlation. The authors hypothesize that designing generalized curriculum may not translate to their students' specific needs, but indicate this as a possible route for future research. These results appear alarming, but there was also an increase of teachers' understanding of student misconceptions for professional developments that involve learning foundational concepts in science.

From the literature reviewed, it is clear that a more thorough investigation as to what makes professional developments effective is necessary. Outlines for effective professional developments for science teachers do exist (Wilson, 2013), but specific models of professional development that improve teacher misconceptions and pedagogical strategies involving misconceptions are poorly understood. The purpose of this study is to examine the efficacy of different models of professional development that target misconceptions. Given the prevalence, persistence, and pedagogical implications of misconceptions, this research seeks to understand methods conducive to addressing them.

## The Present Study

The current study analyzes existing research on professional development and its efficacy in addressing misconceptions. Exhibiting clear improvements from a particular model of professional development will inform professional development content creators, teachers, administrators, and other groups of stakeholders moving forward. While the exact number is disputed, school districts spend billions of dollars on professional development in the United States (TNTP, 2015). Furthermore, pedagogical content knowledge has been linked to effective teaching (Sadler et al., 2013). Since misconceptions are a part of the pedagogical content knowledge framework, investigating methods that improve teacher understanding of misconceptions could give us more insight into how to improve pedagogical content knowledge for teachers in general. For example, Shulman (1986) describes the importance of understanding that students are not "blank slates" and rather come into formal education with an existing framework of understanding the world. As misconceptions are a manifestation of these frameworks, training teachers to adequately address these misconceptions will inherently also address a student's existing understanding of the world and subsequently lead to more meaningful learning.

In order to further the research on professional development regarding misconceptions, this study has examined multiple studies conducted on professional development and its efficacy on improving teacher understanding on misconceptions commonly held by students and teachers alike and improving pedagogical practices concerning misconceptions. Understanding the efficacy of different models of professional development will help educators and professional developers make more informed decisions about how to best remediate misconceptions in education. The purpose of this study is to examine the extent to which different models of professional development aid in educating teachers about misconceptions in science. Specifically, the following research questions are presented:

1. What methods of professional development best address misconceptions held by teachers?
2. Are there differences in the effectiveness of professional developments regarding misconceptions between primary and secondary teachers?

# CHAPTER 2 LITERATURE REVIEW

## ***Defining Misconception***

The term "misconception" is used to describe any belief that a person holds that does not align with current scientific understanding. However, the term implies that we have a complete understanding of scientific phenomena and that all other ideas are incorrect. Consequently, the term has been defined in a multitude of ways throughout the literature. Misconceptions are also referred to in the literature as inaccurate or incomplete ideas (Burgoon et al., 2011), alternative conceptions (Narjaikaew, 2013), non-scientific beliefs (Atasoy et al., 2011), alternative frameworks (Driver, 1981), preconceptions (Hashweh, 1988), and naive beliefs (Stein et al., 2008). Since misconceptions can often form before formal education (Driver et al., 1985), some researchers use the term naive beliefs or preconceptions in place of misconceptions (Morrison & Lederman, 2003). Alternative conception is the term that is used for an idea that is plausible, but is contrary to current scientific knowledge. Finally, alternative framework is a term that Driver used to describe the way in which children build their own cognitive ecology (Driver, 1981). Science is ultimately based on observations, but the observer will view those observations through their own theoretical lens. Since any theoretical framework is manufactured by the observer's own previous experience, there isn't a method for observing phenomena with complete objectivity. Children create expectations about the world based on their previous experiences. Therefore, children's misconceptions about scientific concepts may be thought of as another lens, or alternative framework.

While the nuances of these various definitions of the term misconceptions display clear distinctions, the focus of this research is on the efficacy of dismantling them, rather than how these terms are defined. There are also commonalities between all of these terms, namely that they all would include any belief about a concept that differs from current scientific knowledge as the essences of their terms. Therefore, in order to operationalize the term misconception, all definitions will be used and defined as misconceptions.

***Student Misconceptions***

Much of the research conducted on misconceptions focuses on student misconceptions. Student misconceptions about science are both pervasive and well documented (Driver et al., 1994; Pine et al., 2001). While misconceptions can develop in both primary and secondary education (Mills Shaw et al., 2008; Yates & Marek, 2014; Driver, 1989), the literature indicates that most students have developed their own understandings of science before entering a formal learning environment (Driver et al., 1994; Black & Lucas, 1993; Driver et al. 1985). As stated earlier in the previously delineated term “alternative conception”, children develop these misconceptions by conforming scientific concepts into their own reasoning and previous experience with the world. This common-sense reasoning can actually impede a student’s ability to understand, as more abstract scientific concepts do not necessarily have a common-sense equivalent (Smith et al., 1997). As these ideas are deeply rooted in a student’s framework, misconceptions are stable and can even continue well into adulthood (Driver et al., 1994). This makes it difficult for teachers to dismantle these misconceptions, as misconceptions can remain even after teacher interventions (Driver et al., 1985; Driver et al., 1996).

It is clear from the literature that students have developed their own understanding of the world before entering formal education. However, the sources of a misconception can vary depending upon the specifics of the situation. Kikas (2004) suggests that there are other potential sources of misconceptions that are echoed throughout the literature. First and most obvious, the abstract nature of some scientific concepts give rise to misconceptions because they have no equivalence to daily life (Widiyatmoko & Shimizu, 2018). Kikas (2004) gives the example that students and teachers alike attempt to understand the submolecular world as if it behaved like the macroscopic world they inhabit. Due to the difficulty in conceptualizing these topics, a teacher’s oversimplification of these abstract concepts can actually create misconceptions for students as well. For example, Treagust et al. (2009) states that using submicroscopic and symbolic representations are required in order for effective learning to occur in a high school chemistry course. However, findings in this study conveyed that students do not necessarily understand the representations as their teacher intended them to. On a similar note, textbooks can also give rise to misconceptions by using overly simplified models (Widiyatmoko & Shimizu, 2018). Additionally, textbooks can use confusing language (Gudyanga & Madambi, 2014; Widiyatmoko & Shimizu, 2018). Finally, teachers play an obvious crucial role in the persistence of misconceptions held by students (Widiyatmoko & Shimizu, 2018). A teacher's ability to effectively communicate with their students is crucial in mitigating misconceptions (Gudyanga & Madambi, 2014), as students will continue to build new knowledge based on their misconceptions if left unchecked (Driver, 1989). In addition to communication, teachers also need to administer multiple teaching methods in order to prevent misconceptions (Taber, 2003). Teachers also hold misconceptions themselves and could unknowingly spread their misconceptions to their students (Gudyanga & Madambi, 2014; Widiyatmoko & Shimizu, 2018).

***Teacher Misconceptions***

Unfortunately, teacher misconceptions about science are also persistent in both elementary and secondary schools (Cibik, 2019; Etobro & Banjoko, 2017; Hebe, 2020; Hermita et al., 2017; Rasul et al., 2019). Scientific misconceptions are held across all content areas, from biology (Etobro & Banjoko, 2017; Urey, 2018) to phenology (Kikas, 2004). Stein et al. (2008) states that physical science misconceptions are retained through high school and into adulthood. This is further evidenced by Cibik (2017). This study assessed content knowledge of electric circuits in pre-service science teachers by administering a concept test (Electric Current Concept

Test). Results indicated no significant differences between concept test scores and pre-service teacher's academic year. Qualitative data indicated several common misconceptions regarding electrical circuits. However, this doesn't only apply to the physical sciences. Etobro & Banjoko (2017) administered a genetics concept test to pre-service biology teachers and found that there is no correlation between academic year and their scores on misconceptions. Further, teachers actually have similar misconceptions to their students despite the extensive research on teacher misconceptions (Burgoon et al., 2011). Korur (2015) found that students and pre-service science teachers held the same misconceptions about astronomy. Therefore, it is clear that misconceptions are held by teachers throughout their academic careers. Given that teachers possess similar misconceptions to students, it is therefore likely that teachers share the same sources of their misconceptions as students (Kikas, 2004).

It has been documented that In-service teachers in both primary and secondary settings hold misconceptions. However, elementary school teachers lack content knowledge in science, particularly in the physical sciences (Narjaikaew, 2013; Gomez-Zwiep, 2008; Appleton, 2003; Smith, 2000). Kikas (2004) found that elementary school teachers had significantly more misconceptions about the physical sciences than secondary biology, chemistry, and physics teachers. This is unsurprising, given that secondary science teachers typically possess a richer background in science. Unfortunately, this inadequate science background has caused teachers to be reluctant to teach science (Ngman-Wara & Edem, 2016). It should be noted that secondary science teachers have also been documented to have misconceptions (Liu et al., 2015; Hebe, 2020). Sarieddine & BouJaoude (2014) explored 10 high school biology teachers and their understandings of the nature of science. While some aspects of the nature of science were well understood, nearly all teachers held the misconception that theories can become laws.

Misconceptions are therefore persistent throughout all types of formal educators and apply to all content areas, even the fundamental principles of science itself.

Obviously, it is important for teachers to understand their own misconceptions. Given that teachers' misconceptions can be similar to that of students, they can have obvious impacts on instruction. If teachers are holding misconceptions themselves, how can they help students undergo the difficult process of dismantling an existing worldview? Gudyanga & Madambi (2014) found that teacher misconceptions were a reason for student misconceptions. Therefore, it is likely that teachers are directly transferring their own misconceptions to their students.

In addition to dismantling their own misconceptions, teachers must also be able to identify student misconceptions and understand how to dismantle them. Students' misconceptions are related to instructional practice (Rollnick et al., 2008). Unfortunately, teachers seem unaware of misconceptions or how they can be problematic in shaping a coherent view of complex scientific principles. Ilyas & Saeed (2018) interviewed 15 chemistry teachers and found that most of them could not give a clear definition as to what a misconception was. Additionally, teachers did not identify that misconceptions came from previous understandings that students held. Gomez-Zwiep (2008) found that teachers identified misconceptions as gaps of understanding, rather than a part of a larger framework. This led teachers to ignore students' current understandings after the beginning of the lesson. Ultimately, it is implied here that teachers also seem to lack understanding of their role in conceptual change. In order for a student to abandon their current understanding and accept a new one, teachers need to understand that misconceptions are a part of a larger framework, rather than simply a lack of understanding.

Discouragingly, even teachers capable of correctly identifying common misconceptions may not be capable or willing to address them. Moodley & Gaigher (2019) found that teachers with adequate content knowledge and were aware of student misconceptions did not identify effective teaching methods for addressing them. In other words, content knowledge alone is insufficient for teachers to be able to change a student's existing framework. The implication here being that pedagogical knowledge in science education is necessary for combating student misconceptions.

# CHAPTER 3 METHODS

***Study Design***

The design of this study contains both a meta-analysis and meta-synthesis method. Meta-analysis is a quantitative method which assesses the results of multiple quantitative studies. This analysis allows researchers to combine the results of multiple studies in order to determine the overall effectiveness of a particular variable. By conducting a meta-analysis, I was able to not only see the effects of a particular professional development program, but also see the efficacy of multiple interventions and subsequently attempt to differentiate which aspects of professional development have the greatest impact on teacher misconceptions. Given the broad range of studies conducted on professional development and misconceptions, both qualitative and quantitative studies are equally prevalent to my investigation. Therefore, the meta-synthesis portion of this paper is equally important. Meta-synthesis is a methodological review that forms a coalescence of qualitative findings. This synthesis allows me to find the overarching themes found in many qualitative studies in order to determine recurring aspects of professional development that improve teachers' knowledge of misconceptions as reported in the literature. Additionally, a meta-synthesis will provide more insight into the subjective experiences of teachers participating in professional developments and give a broader perspective from researchers studying teacher misconceptions.

***Collection of Data***

The data corpus for this study are existing published studies focused on misconceptions. A comprehensive search of the literature was conducted in order to acquire studies appropriate for the analysis. Initial review of the literature sorted the studies into categories based on their suitability for meta-analysis and meta-synthesis. In order to identify the studies being used, the following databases were utilized to conduct a preliminary search for relevant articles: ERIC (EBSCO), ProQuest, JSTOR, Scopus, and Google Scholar. I searched for studies focused on misconceptions and professional development that were published between 1991 and 2021. Initially, the search included key terms such as: Efficacy of Professional Development in STEM, Teacher Misconceptions in Science, Professional Development and Misconceptions in STEM, Teacher Learning and Misconceptions, Pedagogical Content Knowledge and Professional Development, Knowledge of Student Misconceptions, and Teacher Learning. After the initial search, major contributors to professional development regarding misconceptions were contacted in order to request additional studies relevant to my investigation (e.g. Cepeda, 2009). After the initial accumulation of 337 articles, I found 35 articles that were relevant to my investigation. Articles were deemed irrelevant to this investigation if there was no relevant focus on professional development or training of teachers. Additionally, studies that did not include treatment and control groups or did not provide measures of efficacy were excluded as not central to this investigation. Lastly, studies that focused on student misconceptions were excluded as not pertaining to the correct population. Finally, I further refined my selection to include only studies that are most relevant to my investigation. During the selection process, several exclusion and inclusion criteria were used. First, theoretical articles or literature reviews were not included because the research questions focus on articles that have results on the efficacy of professional development based on empirical data. Next, I excluded any studies that investigate the prevalence of student misconceptions without reporting on teacher misconceptions. While addressing student misconceptions could be indicative of teacher misconceptions, the current study investigates the efficacy of professional development on teachers. Additionally, only studies that investigate the effect of some form of teacher training have been used. There are many professional development activities that do not measure outcomes. Since this study is measuring efficacy, only studies that describe an outcome were included. Furthermore, given the limited nature of studies on the topic of professional development and misconceptions, several inclusion criteria were implemented. Studies investigating both primary and secondary educators were included. All subjects in science were also included, given that this investigation is concerned with misconceptions in science. In addition, studies that utilize the understanding of student misconceptions as a measurement of a teacher's pedagogical content knowledge were also included. Finally, only papers that included an outcome that was based on content knowledge or procedural knowledge were included. While self-efficacy can be a valid outcome that professional developments would want to measure, it would be inappropriate to compare results of self-efficacy with those that report actual increases in knowledge on misconceptions or the ability to address misconceptions in the classroom. However, self-efficacy was explored as a measure in the meta-synthesis portion of this paper. All data included in this study were either from multiple choice questions where misconceptions were used as detractors, or classroom observational data on a teacher's ability to identify and address misconceptions. After implementing these exclusion criteria, 31 of the 337 initial studies found were excluded. Therefore, 4 studies were used for the meta-analysis portion of this paper. Finally, both quantitative and qualitative studies were included for the meta-synthesis portion of this paper. Meta-analysis only includes quantitative studies, but both can be utilized in order to conduct a meta-synthesis. 6 articles were selected for the meta-synthesis portion of this paper.

***Coding***

Coding each of the articles includes a quantitative and qualitative reviewing process. Quantitative studies were coded for measurable outcomes, such as pre and post test scores on misconceptions and knowledge of student misconceptions. Coding also included demographic data. While these common themes are only revealed after investigating the studies obtained, coding includes pertinent characteristics to our research questions. Such codes include: the model of professional development used, professional development's effect on knowledge of student misconceptions, professional development's effect on alleviating teacher misconceptions, whether the professional development was offered to primary or secondary teachers, and professional development's effect on instructional practice regarding misconceptions.

Additionally, each of the professional developments were categorized into two different groups based on whether their professional development program was more content focused or more pedagogy focused. During this coding process, key terms were coded for in order to determine which type of professional development was offered. Additionally, the structure of the study also determined whether content or pedagogy was at the heart of the professional development offered. For example, papers that included phrases such as "heavy emphasis on academic material" were coded as more content focus, while papers with phrases such as "focuses on making students' thinking visible through talk and argument" were coded for as more pedagogy focused. Additionally, one paper had three different professional development interventions, which all had the same science content, but different pedagogical training strategies. Therefore, these three interventions were coded for more pedagogically focused, as that was their independent variable (Heller et al., 2012). This is not to say that these interventions were solely content or pedagogy, as these studies had elements of both. However, as these studies rely on similar constructive principles, their differences can be elucidated with this coding scheme on emphasis.

***Analysis***

Over the course of analyzing the papers that were included, some challenges became apparent. While some of the papers included effect sizes, the effect sizes reported were different from study to study (partial eta squared, customized for model, unspecified, etc.). Therefore, effect sizes needed to be standardized in order to aggregate quantitative data for comparison. Cohen's d is an effect size that can be utilized to compare effects across studies (Lakens, 2013). The means and standard deviations of each paper were used to calculate Cohen's d in order to make a meaningful comparison. According to Cohen (1988), effect sizes of 0.2 are small, 0.5 are medium, and 0.8 are large. Additionally, some of the studies used were pre-experimental in their design (Jansri & Ketpichainarong, 2020). It would therefore be inappropriate to compare the effect sizes from a control group and treatment group to those studies that did not have a control group. Accordingly, effect sizes were only calculated from pre and post test data from the experimental groups in those studies that contained a control group. This ensures that only repeated measurements from each study are compared. Some studies did have follow up assessments for misconceptions. However, due to the fact that some studies only tested directly after the professional development, only data from directly after the interventions were used for comparison. Finally, two of these studies held multiple professional development interventions (Cepeda, 2009; Heller et al., 2012). Due to the already small sample size and the fact that all of the interventions individually could be included using my criteria, these interventions were analyzed separately.

Unfortunately, due to the extremely small sample in this meta-analysis, it would be inappropriate to conduct a full statistical analysis. Consequently, descriptive statistics are used as a means of explaining my results. Therefore, this study cannot be used to generalize the efficacy of professional interventions on the mitigation of misconceptions. However, it can still be a useful tool in furthering my exploration into what aspects of professional development addresses misconceptions.

For the meta-synthesis portion of this paper, the results were investigated under the seven topics of meta-synthesis (Yildirim, 2016). The first stage involves the selection of an area of study. This meta-synthesis focuses on the efficacy of professional development in dismantling teacher misconceptions and improving a teacher's knowledge and instructional practices on student misconceptions. The second stage is selecting the literature that was used in the meta-synthesis. The third stage is reading the data. The fourth stage is determining how the data from multiple studies are connected. Comparisons between studies were made based on their keywords, concepts, and conclusions. These findings were specified and listed. The fifth stage involves converting the data. The sixth stage is abstracting key concepts from the data reviewed. The seventh stage is synthesizing the data into an overall conclusion.

***Validity***

Validity for meta-analysis involves the proper selection of studies for my investigation. First, I ensured that all studies are filtered by using my inclusion and exclusion criteria described previously. The second part of selecting valid studies involves determining if effect sizes are reported or if they can be calculated. This screening process ensures that only appropriate studies are selected and compared. Studies that did not report the descriptive statistics necessary to calculate Cohen's d were not included in this study.

For the meta-synthesis portion of this study, establishing validity would be important, as any meaningful results require the preservation of each study's conclusions and ideas. Sandelowski and Barroso (2007) describes three measures of validity regarding meta-synthesis. Descriptive validity is achieved when the data used adheres to the results found by each of the articles. When coding for overall themes, I ensured that I was only presenting factual information from the articles selected. Interpretive validity is ensuring that any conclusions that I used for meta-synthesis accurately reflect those conclusions stated by the articles. It is important that all interpretations made by researchers are precisely represented. Lastly, institutional validity ensures that the method used in data analysis is followed during data analysis. This ensures that the interpretation of the results is valid.

# CHAPTER 4 RESULTS

## *Research Question 1*

The first research question was "What methods of professional development best address misconceptions held by teachers?" In order to attempt to answer this question, each professional development was categorized into either a content or pedagogy focused intervention (see Table 1). Each of the professional developments' post treatment effect sizes were then used to calculate the mean effect size for each type. Hedge's g is also reported for Heller et al. (2012) due to differences in sample sizes for transparency (Table 2). The mean value of Cohen's d for content focused professional developments is 1.95 (SD=0.82) and is 1.91 (SD=0.28) for the professional developments focused on pedagogy (see Table 3 for mean effect sizes).

Again, the results here are too small to conduct a full statistical analysis. Therefore, these results should not be generalized. However, it is clear that there are no significant differences between the pedagogy focused professional developments and content focused professional developments. Content focused professional developments have a slightly higher mean effect size, but the pedagogy focused mean effect size is within one standard deviation. These professional developments varied widely in their content, from misconceptions in general to focusing specifically on the revolution of the Earth around the Sun. There does seem to be a small correlation between the specificity of the professional development and how large the overall effect size was. The largest effect size shown was the professional development that involved the revolution of celestial bodies, a very specific topic in astronomy. Nevertheless, what all of these studies did have in common was a large effect size. Each one of these professional development models had significant differences from pre and post test data on the topic of misconceptions. This is not to say that all misconceptions were alleviated from these interventions, but they certainly did benefit the teachers that participated. Even the smallest effect size reported is well above the 0.8 threshold for a large effect size in Cohen's d.

Although the effect sizes were larger in one of the intensive and short professional development models, there does not seem to be a correlation between duration of the professional development and the efficacy of the professional development on misconceptions either. With the post test data collection taking place directly after the professional development (no follow-up testing data was used), one might expect the shorter professional developments to have a higher effect size, given that it would be fresher on the teachers' minds. However, although the highest effect size reported was also the shortest professional development, the three-year long program had a larger effect size than one that only lasted two weeks. Therefore, from this small data set, it would seem that duration may not impact the overall effect size.

**Table 1:** All Studies Used and Their Corresponding Publication Type, Interventions Used, and Categories

| Article | Publication Type | Professional Development Model Used | Professional Development Length | Category |
|---|---|---|---|---|
| Heller et al. (2012) | Journal Article | Looking at Student Work, Metacognitive Analysis, Teaching Cases | 14 weeks (some during a 1 week summer course) | Pedagogically Focused |
| Cepeda (2009) | Dissertation | Biology Class 1, Biology Class 2 | 2 weeks | Content Focused |
| Jansri & Ketpichainarong (2020) | Journal Article | Astronomy Professional Development | 4 days | Content Focused |
| Hauck (2012) | Dissertation | 3 Year Sustained Professional Development Program | 3 years | Pedagogically Focused |

**Table 2:** Interventions and Effect Sizes by Their Corresponding Study

| Article | Intervention | Cohen's d | Hedge's g | Sample Size |
|---|---|---|---|---|
| Heller et al. (2012) | Teaching Cases | 1.99 | 1.99 | Pre: 67 Post: 69 |
| Heller et al. (2012) | Looking at Student Work | 2.32 | 2.30 | Pre: 69 Post: 63 |
| Heller et al. (2012) | Metacognitive Analysis | 1.75 | 1.73 | Pre: 65 Post: 56 |
| Cepeda (2009) | Biology Class 1 | 1.45 | 1.45 | 21 |
| Cepeda (2009) | Biology Class 2 | 1.29 | 1.29 | 20 |
| Jansri & Ketpichainarong (2020) | Astronomy Professional Development | 3.11 | 3.11 | 45 |
| Hauck (2012) | 3 Year Sustained Professional Development Program | 1.58 | 1.58 | 22 |

**Table 3:** Mean Effect Sizes and Standard Deviations by Professional Development Category

| Category | Number of Interventions | Mean Effect Size (Cohen's d) | Standard Deviation |
|---|---|---|---|
| Content Focused | 3 | 1.95 | 0.82 |
| Pedagogically Focused | 4 | 1.91 | 0.28 |

The articles selected for meta-synthesis were also coded for professional development approach and are listed in Table 4. From synthesizing these articles, it is evident that learning science content was the primary driver for mitigating misconceptions. This is shown because learning content was the primary need identified in Friedrichsen et al. (2016) and because all of the articles but one demonstrated how learning from tertiary instructors, actual scientists, or spent time learning foundational concepts all led to mitigating teacher misconceptions. However, some pedagogically focused professional developments, such as focusing on discourse patterns in the classroom, yielded promising results.

It is worth noting that within the research approaches to professional development varied widely. However, most of the articles focused on learning science content to improve their knowledge on misconceptions. Quantitative articles that could not be used for direct comparison in the meta-analysis portion of this paper largely focused on aspects of professional development that were effective (e.g. Doyle et al., 2018), or focused on the self-reported professional development needs of science teachers (e.g. Friedrichsen et al., 2016). From these articles, it is clear that more content learning is paramount to mitigating misconceptions. Science teachers reported that they needed more support in learning more contemporary examples of the content that they are teaching (Friedrichsen et al., 2016). Additionally, teachers that reported learning about foundational science concepts in their professional developments also had a better understanding of misconceptions (Doyle et al., 2018). Teachers also were aided by having an expert teach them science content, particularly when it comes to mitigating misconceptions on the nature of science (McLaughlin & MacFadden, 2014; Schrein et al., 2009).

While the majority of the articles focused on improving misconception knowledge through content learning, several articles also described the ways in which pedagogically focused professional developments could help teachers overcome their misconceptions. In particular, one study focused on an expert-led professional development in which elementary school teachers practiced discourse patterns as a means of understanding social interaction and subsequently understanding how to talk about misconceptions in the classroom (Oliveira, 2009). This finding could be of value to both elementary and secondary teachers. Knowing that a misconception exists might be the first step in mitigating misconceptions, but knowing how to approach a student misconception in the classroom would be an equally vital component. Additionally, some of the professional development models incorporated pedagogically based activities that very well could have helped teachers greatly in understanding misconceptions. Therefore, an overall theme of these results indicated an emphasis on pedagogical content knowledge.

**Table 4:** Articles Coded for Professional Development Approach, Category, Outcomes, Subject, and Sample Size.

| Article | | Professional Development Approach | Outcomes | Subject | Sample Size |
|---|---|---|---|---|---|
| McLaughlin & MacFadden (2014) | | Increase content knowledge through a travel experience with actual scientists | With support, teachers improved their understanding of the nature of science. | Life Science | 5 |
| Oliveira (2009) | | Focusing on teacher social understandings and discourse | Teachers were able to identify better discourse strategies when addressing student misconceptions. | Life Science | 15 |
| Friedrichsen et al. (2016) | | Teachers self-reporting their PD needs | Teachers need support in both teaching materials and more content training on contemporary examples of evolution. | Life Science | 276 |
| Schrein et al. (2009) | | Content learning from tertiary instructors | Teacher surveys on the misconceptions portion of the training were very positive. | Life Science | 13 |
| Rasul et al. (2019) | | 5E Learning Model | Teachers that participated in this PD scored significantly higher on a misconceptions test than the control. | Physics | 96 |
| Doyle et al. (2018) | | Learning foundational science concepts (selfreported) | Only PDs that focused on learning foundational science concepts were positively correlated to knowledge on misconceptions. | Multiple Science Subjects | 1858 |

***Research Question 2***

The second research question was “Are there differences in the effectiveness of professional developments regarding misconceptions between primary and secondary teachers?” Interestingly, all of the more pedagogy focused professional developments were also the ones that offered their professional development to elementary school teachers, while the content focused professional developments were offered to the secondary teachers (see Table 5). This is noteworthy because of the well-known lack of science content knowledge in elementary school teachers (Gomez-Zweip, 2008). This is not to say that those professional development categorized as pedagogically focused did not include any science content, but the emphasis on pedagogy was clear by either spending more time on pedagogical content, or using pedagogical methodology as the independent variable of the study.

From the results displayed in Table 5, it is shown that there are no significant differences between the secondary and elementary teacher professional development mean effect sizes. While this cannot be generalized, it does yield an interesting result for the context of this study. It appears that both secondary and primary teachers greatly benefit from professional development that directly deals with misconceptions. It would seem that professional development can make a massive difference in teacher-held misconceptions, regardless of how trained teachers are in science content areas. While I might expect greater mean effect sizes for elementary school teachers learning about misconceptions directly through these professional developments, given that they have less training in the sciences, the evidence here demonstrates that secondary teachers had an equally large effect size in gains by taking professional developments that address misconceptions.

Finally, since all but Hauck (2012) were multiple choice questions on knowledge of misconceptions, it could be argued that procedural knowledge in the classroom should not be compared to these multiple-choice questions. The multiple-choice questions determined if teachers were aware of the misconception, while identifying a student misconception and addressing it arguably includes more factors (e.g. classroom dynamics). If I omit Hauck (2012) from the comparison the new mean effect size is 2.03 (SD=0.23). Even with the elimination of procedural data, the mean effect sizes are still not significantly different and are within one standard deviation.

**Table 5:** Teacher Type by Professional Development Model

| Article | Professional Development Model Used | Primary or Secondary Professional Development | Category |
|---|---|---|---|
| Heller et al. (2012) | Looking at Student Work, Metacognitive Analysis, Teaching Cases | Primary | Pedagogically Focused |
| Cepeda (2009) | Biology Class 1, Biology Class 2 | Secondary | Content Focused |
| Jansri & Ketpichainarong (2020) | Astronomy Professional Development | Secondary | Content Focused |
| Hauck (2012) | 3 Year Sustained Professional Development Program | Primary | Pedagogically Focused |

**Table 6:** Mean Effect Size by Teaching Category

| Teaching Category | Number of Interventions | Mean Effect Size (Cohen's d) | Standard Deviation |
|---|---|---|---|
| Secondary | 3 | 1.95 | 0.82 |
| Primary | 4 | 1.91 | 0.28 |

**Table 7:** Mean Effect Sizes of Multiple-Choice Assessments Only

| Teaching Category | Number of Interventions | Mean Effect Size (Cohen's d) | Standard Deviation |
|---|---|---|---|
| Secondary | 3 | 1.95 | 0.82 |
| Primary | 3 | 2.02 | 0.23 |

The articles were also coded for which grade level of teacher and are displayed on Table 8. Most of the articles coded involved secondary teachers. However, it is interesting to note that the only professional development offered only to elementary teachers was centered on pedagogy. The same is true for the meta-analysis portion of this paper. These articles also demonstrate how much both elementary and secondary teachers can benefit from content focused professional developments. The only study that contained both secondary and elementary school teachers found that professional developments that involved learning foundational science content benefited teacher's knowledge on misconceptions (Doyle et al., 2018). This is further supported by the qualitative articles that were written pertaining to learning content. From these studies it is unclear whether or not professional developments regarding misconceptions are more effective for either elementary or secondary teachers, but from all of the articles discussed in this paper, it appears that secondary teachers are given more content-based opportunities. The results indicate much more pedagogically focused professional developments for elementary school teachers, while secondary teachers are offered more content heavy professional developments.

**Table 8:** Articles Coded by Approach and Teaching Category

| Article | Professional Development Approach | Primary or Secondary Professional Development | Pre-service or Inservice Teachers |
|---|---|---|---|
| McLaughlin & MacFadden (2014) | Increase content knowledge through a travel experience with actual scientists | Secondary | In-service |
| Oliveira (2009) | Focusing on teacher social understandings and discourse | Primary | In-service |
| Friedrichsen et al. (2016) | Teachers self-reporting their PD needs | Secondary | In-service |
| Schrein et al. (2009) | Content learning from tertiary instructors | Secondary | In-service |
| Rasul et al. (2019) | 5E Learning Model | Secondary | Pre-service |
| Doyle et al. (2018) | Learning foundational science concepts (self-reported) | Both | In-service |

# CHAPTER 5

## Discussion

The most important implication of this review of the literature is that there is a clear lack of research on how to mitigate science teacher misconceptions. The literature clearly establishes that teachers at both the secondary and primary levels harbor misconceptions (Cibik, 2019; Etobro & Banjoko, 2017; Hebe, 2020; Hermita et al., 2017; Rasul et al., 2019). However, there seems to be a dearth in the literature as to how to go about dismantling and correcting misconceptions that teachers have. The papers used in this meta-analysis demonstrate promising results in addressing teacher misconceptions. Therefore, while the literature on identifying teacher misconceptions in science is quite clear, the literature on how we might move forward with a plan to mitigate these misconceptions is sparse. While multiple papers have promising results with professional developments for mitigating misconceptions (Rasul et al., 2019) the fact remains that there is not enough evidence to make a strong case for the types of professional development that would be the most effective. This paper provides a small sample of promising methods that could be used going forward in the design of professional development regarding science misconceptions, and increasing science content and pedagogical content knowledge.

In addition to the fact that there aren't enough studies on mitigating misconceptions through professional development, the professional developments regarding misconceptions moving forward should include instruments that determine how effective they are. Moyer-Packenham et al. (2011) found that almost 80% of professional developments do not report using any instruments at all to determine efficacy. This data would be imperative to determining which types of models of professional developments are the most effective, not only regarding misconceptions, but many other aspects of professional development. Furthermore, professional development articles should also list the descriptive statistics necessary for comparison. Without explicitly listing descriptive statistics, meaningful comparisons between professional developments cannot always be made.

In addition to making desired outcomes and measures of those outcomes clear, professional development and research on professional development should make clear which models they are using. As we have already discovered the many misconceptions that teachers harbor, the hope of each professional development intervention is to demonstrate the positive effects that its particular model has on those misconceptions. While these studies demonstrate this efficacy within the context of its own study, it is difficult to generalize these findings to a larger scale with a limited description of these professional development models. The studies used in this paper did describe their professional development model well, such as the Learning Cycle Theory described in Jansri & Ketpichainarong (2020). Unfortunately, some studies are very minimal in their descriptions of their interventions and do not make their particular model clear.

While instruments and explicitly listing models used would aid in generalizing findings, studies also should provide the descriptive statistics necessary to make meaningful comparisons between studies. Data from individual studies are what make meta-analysis and, subsequently, generalizing the literature possible. However, the wide range of effect sizes and other data presented within a single study make comparisons difficult (Lakens, 2013). As stated, some effect sizes are not appropriate for comparison across studies. Therefore, studies regarding efficacy should list the full descriptive statistics either within the paper or as a supplemental material in order to contribute to future meta-analyses.

The results presented in this paper at least demonstrate some promising results for the efficacy of professional developments of varying models and targets for mitigating teacher misconceptions. Burgoon et al. (2011) found that elementary teachers still harbor the same misconceptions as their students, the implication being that teachers still harbor misconceptions even after decades of research. However, this paper has clearly demonstrated that there are professional developments that exist which do an excellent job of addressing teacher misconceptions at both the elementary and secondary levels. Cohen (1992) states that an effect size of 0.8 is considered large. All of these studies demonstrated a large effect size and therefore have a great deal of merit in their accomplishments, regardless of the model used. By utilizing aspects of the professional development used in this paper, increasing the use of instruments in professional developments, and explicitly listing data, future studies can move past the identification of misconceptions into mitigating misconceptions.

***Pedagogical Content Knowledge***

The results from this study demonstrate that there were no significant differences in the categorization of pedagogically focused professional developments and content focused professional developments. While this study did not find any differences between models of professional development, it is clear that these professional developments were effective. When the evidence from this study is applied to a pedagogical content knowledge model, it makes sense that professional developments should include elements of both content and pedagogy. The results from this study bolster the idea that misconceptions are within the framework of pedagogical content knowledge, as described by Shulman (1986).

Teachers need content knowledge in order to properly understand why a held misconception is a misconception. You cannot identify what you don’t know in the first place. Since teachers have demonstrated a multitude of misconceptions across disciplines, it is clear that teachers need more content training. Most of the studies used in this meta-analysis indicated elements of constructivism as their mechanism of teaching teachers more content. Most studies used in this paper used inquiry as a primary driver and then supplemented with information.

Along with content, teachers also need training in pedagogy. It is one thing to understand that a misconception is a misconception, but it is another to have the ability to identify and mitigate a misconception in the classroom setting. The pedagogy focused professional developments all utilized looking at students' methods of thinking and identifying how instructional strategies have effects on student learning over time. This hints at being able to identify how misconceptions function in the cognitive environment of students. The instructional strategies that teachers use will have a large impact on students' conceptual framework. Professional developments in the future can learn from this small sample by making the learning strategies involved very clear and explicitly discussing how misconceptions function within a student's learning process.

***Both Primary and Secondary Teachers Need Content Training***

It is surprising that, even with this small sample size, that secondary teachers seemed to benefit from professional developments that focus on misconceptions as much as elementary teachers. As described previously, elementary teachers have far less training in science than secondary teachers do (Narjaikaew, 2013; Gomez-Zwiep, 2008; Appleton, 2003; Smith, 2000). Previous studies have determined that secondary teachers might not have the pedagogical knowledge to teach their disciplines effectively (Abd-El-Khalick et al.,1997). This might lead some to the conclusion that secondary science teachers need more pedagogical training than content training. One might assume that because secondary teachers have taken more science courses, that they might not need training in science content. However, it would seem that content focused professional learning does have a positive impact on secondary teachers' understanding of misconceptions. From these studies, it was clear that secondary teachers harbored misconceptions before professional development. Furthermore, Cepeda (2009) found that middle school teachers lacked a conceptual understanding of the nature of science in general.

Due to the findings of this study, and the myriad of studies that have identified that secondary teachers still have misconceptions in science (Liu et al., 2015; Hebe, 2020; Sarieddine & BouJaoude 2014), it is clear that secondary teachers need further content training. When discussing having the pedagogical content knowledge necessary to teach science subjects at the secondary level, it is important for us to understand the wild breadth and depth of science content knowledge that may be necessary in order to teach science effectively. Furthermore, one should not assume that every secondary science teacher has a well-developed background knowledge in the subject area that they teach. For example, Jansri & Ketpichainarong (2020) found that, of their 45 high school teachers that were teaching astronomy, none of them had a background in astronomy. Secondary teachers may need more coursework and testing in order to teach science, but that does not necessarily mean that they have the background knowledge necessary to have working pedagogical content knowledge. Therefore, a small recommendation from this paper would be to further emphasize learning science content at a deeper level for secondary science teachers.

Secondary teachers may still need content training, but the evidence here makes the case that elementary teachers need to be offered more content training. Given that elementary teachers lack training in science, it is important to offer them more professional developments with a focus on in depth content. All of the studies in both the meta-analysis and meta-synthesis portion of this paper indicate that elementary teachers are not being offered content focused professional developments. While pedagogy is absolutely necessary for effective teaching, elementary school teachers also need to understand the content that they are teaching. It is clear from this study that teachers have a better understanding of common misconceptions from learning science content, particularly on the nature of science itself. Therefore, another recommendation that this paper suggests is to offer more professional developments that teach elementary teachers science content.

***Limitations***

The largest limitation to this study is, of course, sample size. No statistical analysis was able to be conducted due to the small sample size and therefore these results cannot be generalized. Furthermore, there were small sample sizes in the studies that were used for this meta-analysis. Next, only pre and post data was used in this study. Therefore, no control groups were able to be used as a comparison to the effects of the interventions on the experimental groups. Additionally, since the professional developments utilized both pedagogical and content knowledge strategies, it is difficult to distinguish between how effective one strategy was, even if the emphasis was on a particular strategy. Finally, since professional developments can vary widely in both the measurements used and the measurements reported, not all useful data in some papers could be included.

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