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Meta-Analysis on the Effects of Teaching Methods on Academic Performance in Chemistry

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This study utilized the quantitative meta-analysis technique to integrate chemistry education research findings conducted in the Philippines covering the period 2005 – 2016. It aimed to describe and examine the effects of teaching methodologies on academic performance in the secondary chemistry teaching-learning process. A search procedure and broad literature review were conducted to identify the potential and qualified chemistry studies from both published and unpublished graduate theses, dissertations and journal articles. Meta-analysis was effectively and systematically carried out through study acquisition, study coding, determination of inter-rater reliability, establishing inclusion criteria, computation of effect size including mean and interpreting the analyses. A total of 51 studies met the criteria and have qualified in the meta-analysis. Results presented that a statistically significant positive effect (Cohen's d = 1.208) was observed in the use of teaching interventions on academic performance. The findings affirmed the effectiveness of the use of varied teaching strategies in chemistry education toward student achievement in contrast to the traditional teaching method. The meta-analytic review revealed that during the last decade, the incorporation of other avenues of learning via innovative teaching methods promotes academic gain. As far as quality of instruction is concerned, the findings give a holistic understanding of the current educational practices in chemistry instruction that would serve as basis for future educational reforms.

Keywords: chemistry education, meta-analysis review, teaching method, academic achievement, effect size

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INTRODUCTION

Most reforms in chemistry education call for an emphasis on improving teaching quality and effectiveness. Blazar and Kraft (2016) presented that the role of teachers has a profound effect on student growth and learning success. The expected role of a teacher in the traditional manner is a content expert who can impart his or her knowledge to students and shifts to a newer orientation that teachers should act as a facilitator of the learning process (Edomwonyi-otu, 2011). Chemistry teaching is supposed to be result-oriented and student-centered, and this can only be achieved when students are willing and the teachers are favorably prepared to use the appropriate methods and resources in teaching the students (Edomwonyi-otu, 2011).

Various teaching methods/strategies like cooperative, inquiry-based, problem-based and project-based learning have been introduced and adopted by chemistry educators and researchers as considering ways and means of ensuring effective teaching and learning in school (Aktamis et al, 2016; Ayaz & Sekerci, 2015; Caliskan, 2004; Capar & Tarim, 2015; Dagyar & Demirel, 2016; Johnsen, 2009; Maxwell et al, 2015). However, questions concerning the effectiveness of teaching methods on student learning have raised considerable interest in the field of educational research (Ganyaupfu, 2013). Chemistry educators and researchers continually made efforts in conducting relevant studies that dealt with teaching-learning strategies, assessment on student outcomes, intellectual and non-intellectual learning skills and others. The accessible large body of literature and periodic outputs of graduate students in the higher educational institution are manifestations of these endeavors. However, observation shows that findings are rarely applied in actual teaching. These educational researches provide reliable findings that pose an aim to give knowledge on the present status and to improve the chemistry teaching-learning process in school. Therefore, there is a need to collect, integrate, synthesize and repeatedly meta-analyze existing chemistry research findings to better inform teachers and educators.

Meta-analysis is a formal, quantitative and systematic study design that integrates the results of previous research studies. This statistical procedure plays an important role in various fields, particularly education (Haidich, 2010). This approach simply combines data and summarizes findings of independent studies to evaluate the effectiveness or efficacy of a similar treatment approach to a similar group of respondents (Israel & Richter, 2011). The research implies that the generated empirical evidence supports the effectiveness of alternative teaching strategies in science. Researchers shifted to the area of meta-analysis in the different areas of education such as in-service professional development programs (Egert et al., 2018), reading for writing (Graham et al., 2018), teacher-student interactions (Vandenbroucke et al., 2018), children with poor reading comprehension (Spencer & Wagner, 2018), interactive distance education (Cavanaugh,2001) and teaching strategies on student achievement in chemistry (Okwuduba & Okigbo, 2018), mathematics (Capar & Tarim, 2015; Haas, 2005; Kalaian & Kasim, 2014; Ugwuanyi, 2015), and science (Schroeder et al., 2007).

Research that deals with meta-analysis of chemistry education research findings are a pioneer across the available secondary chemistry educational researches in the

Philippines. Most of the educational researches conducted does not involve meta-analysis of findings rather empirical studies are abundant. Meta-analysis is still a less explored research territory within the country. Optimistically, we see the need to undertake this study and look into the significant contribution to the improvement in the field of educational research and chemistry education. In the hope to provide a current status of chemistry education in the Philippines, it is important to examine the type of methods/strategies used and how it effectively fits into the students' needs and characteristics.

Objectives of the Study

In light of the lack of previous meta-analyses on the issue, we sought to integrate and meta-analyze chemistry education research findings covering the period 2005-2016. Our study described and determined whether the use of teaching methodologies significantly contribute to academic performance in secondary chemistry teaching-learning process based on the chemistry education research findings. Specifically, the focus was to determine the overall effect of the chemistry education studies qualified in the meta-analysis with regards to the use of teaching methods on academic performance. Likewise, we identified the teaching method categories that appear to have the largest effect size to academic performance.

METHOD

Research Design

Meta-analysis offered a way to broaden the search, examining all available studies (published and unpublished) at once, so that an overall effect size would be calculated. We employed a combination of qualitative and quantitative approaches to examine the relationship between teaching methodologies and academic performance in chemistry education. The qualitative aspect involved the coding of chemistry education research findings or hyper-analysis mapping of meta-analysis results. On the other hand, studies of impact were quantitatively synthesized using a meta-analysis technique to produce a big picture of influence among variables.

Research Locale

The chemistry education research findings of both published and unpublished studies were collected nationwide in the Philippines to avoid publication bias. The search was systematically done in both private and state universities offering graduate chemistry education and teaching program. We conducted a broad search of a possible pool of studies related to chemistry instruction throughout the Philippines and through or by online browsing.

Data Sources

A total of 149 empirical studies were gathered from theses, dissertations and journal articles in the field of chemistry education. Fifty-one (51) studies with 12 published and 39 unpublished were qualified in the meta-analysis based on the framework of the established inclusion criteria. The qualified empirical studies in chemistry education were reviewed and coded based on the characteristics or features.

Research Instruments

1) Study qualifying sheets

The sheets were developed for each case of chemistry education that served as a basis for qualifying the study during the pre-screening process. It contained the set of criteria specified in selecting the appropriate study.

2) Coding sheets

The sheets were adapted (Cavanaugh, 1998) for each case of chemistry education research findings. These were modified based on the inclusion criteria being set as well as the classes of variables (i.e. publication year, the locale of the study, intervention, etc.). The information taken from these sheets were tabulated and used in the meta-analysis as well as in plotting the mapping matrices in the different categorization.

3) Data lay-out matrix

This matrix was used to summarize the information taken from the coding sheets and to facilitate the systematic analysis of chemistry education research findings.

4) Mapping matrices

These matrices were developed for an independent or dependent variable based on the different sub-categories of such variables. It was simply utilized to plot the different variables based on their sub-categories. We were responsible for facilitating the groupings of variables, in comparing the dataset of each outcome variable and in the ranking of the effect size as to determine the categories of teaching methods (independent variables) that demonstrated as the most influencing factor to student academic performance.

Data Gathering Procedures

1) Identification and collection of potential studies

Empirical studies involving academic performance as affected or influenced by different teaching methodologies were assembled. This pool of studies includes a particular case of research findings that deals only on the effects of teaching methodologies on academic performance. We conducted a search procedure and broad literature review to identify the potential and qualified chemistry education studies from the published and unpublished graduate theses and dissertations. Moreover, a computerized search was also executed from the following; journals of educational organizations for both foreign and local, electronic search through ERIC (Education Resource Information Center) database and search terms using standard search engines Google and Google Scholar.

2) Pre-screening

The surface level screening was performed in each of the gathered chemistry education. In the case where the essential study characteristics were not evident from the title and abstract, the full text was examined. Several rigorous criteria were employed for the inclusion of studies in this synthesis. The following criteria includes studies: 1) focused on academic performance as resulting from the use of chemistry education teaching methods, 2) completed between 2005 and 2016, 3) conducted or carried out in the Philippines, 4) involved only in secondary chemistry academic domain, 5) utilized the experimental or quasi-experimental research design, 6) reported effect size (ES) or contained statistical details necessary to calculate effect size (ES) such as mean, standard deviations, sample size, t, f and p values, ANOVA tables, degree of freedom (df), etc. After an extensive literature review, a total of 51 studies, which fit the inclusion criteria and the required source of data for the meta-analysis were identified. The meta-analysis studied the relationships between the dependent variables and the potentially contributing independent variables (Cavanaugh, 1998). To explore some of the heterogeneity of effect sizes among the research findings, identified teaching methods were cast into treatment categories that act as the independent variable of this study. On the other hand, the dependent variable of this meta-analysis was academic performance as affected by the teaching method categories.

3) Coding process

We coded all the gathered studies together with Ph.D. level professionals in science education. We performed the coding process separately using a coding scheme with the study features. The coding sheets were developed to delineate each study features based on the data extracted. Hence, we gave careful attention to qualified studies as these served as the framework for analysis. Thus, we coded each case of chemistry education research findings. Each coding sheet was constantly refined as the synthesis proceeded. Both qualitative and quantitative information was coded using the sample coding sheet to permit the comparison of findings across studies. The table for a quantitative description of the different characteristics included in the case of the study was provided to the coders. The data extracted from each study were coded according to the features of the study. Treatment categories were used in the study as a comparison of the effectiveness of different teaching methods as they influenced student performance.

4) Content validation

Content validation was performed on the instruments used in the meta-analysis. The content validation process was conducted by three experts whose expertise and experience in the following fields; science education, statistics, and assessment and evaluation. The instruments were examined by the experts individually. Corrections and suggestions made were collectively integrated for the final construct and refinement of the instruments.

5) Test for reliability

Reliability checks were performed on the study coding and mapping processes and used percent agreement. This measure provides the average percentage agreement on coding samples between independent coders. A sample of three studies was randomly chosen and used to compute the percent agreement and code for all studies which were then compared item by item. All the qualified studies were reviewed and coded individually by the researcher together with two science educators (a Ph.D. and a master’s degree holder) with a strong background in statistics. To guarantee the reliability of the study, it was found that the degree of agreement between coders was 89.85%. As cited by Ayaz & Sekerci (2015), the values obtained from 70% and above are considered sufficient for the reliability criteria. Items disagreeing the coders were re-examined and resolved through discussion and mutual decision.

Data Analysis

Study coding and data were compiled using a Microsoft Excel Spreadsheet to collect and organize the data. Moreover, an excel form was created to prompt for all needed features for each study and automatically save the information in a database from which analyses would be conducted. The data were analyzed using the Comprehensive Meta-analysis Program/Software. Compute effect sizes for study, differentiate and determine weighted effect size for each study, the test of homogeneity, and mean effect sizes were the statistical computation performed in the meta-analysis.

FINDINGS

Frequency Distribution of Qualified on Academic Performance

The meta-analysis results for the studies investigating the effects of the treatment category tailored to students' academic performance is presented in Table 1.

Table 1
Frequency Distribution of Qualified Studies on Academic Performance

Treatment Categories	n (No. of Studies)	Percentage (%)
Inquiry-based Learning	11	21.57
Manipulative, Models and Multiple Representations	10	19.61
Cooperative Learning	9	17.65
Technology-aided Instruction	6	11.76
Individualized Instruction	5	9.80
Problem-based Learning	4	7.84
Project-based Learning	3	5.88
Combination Learning	2	3.92
Multicultural Education	1	1.96
Total Studies	51	100

As seen in the table, inquiry-based learning (n = 11), manipulative, models and multiple representations occupy the top teaching methods being studied on academic performance in chemistry. It was followed by cooperative learning and technology-aided instruction with nine (n = 9) and six (n = 6) qualified studies, respectively. There were only five (5) primary studies qualified that fall under individualized instruction and four (n = 4) studies on problem-based learning. The least studied type of teaching methods include project-based learning (n = 3), combination learning (n = 2) and multicultural education (n = 1).

Meta-analysis for All Studies

Using the random-effects model the computed mean effect size for 51 studies is 1.208, SE = 0.115 as seen in Table 2. At a confidence level of 0.05, the 95% confidence limit was determined. The confidence limits were 0.984 to 1.433 that implies that the null hypothesis of the population effect size is zero can be rejected. Confidence intervals of continuous measures that include zero represent non-significant results (Israel & Richter, 2011). This shows that the mean effect size of teaching methods on academic performance in chemistry is high and positive.

Table 2
Meta-Analysis for All Studies

Over-all Effects	Mean ES	Mean SE	Lower Limit	Upper Limit	Z value	P value
51 Studies	1.208	0.115	0.984	1.433	10.534	0.000*

*p<0.05

Effects of Treatment Categories on Academic Performance

In the meta-analysis, all innovative teaching methods presented in Table 3 exhibited a significant positive influence ($p < 0.05$) in terms of their mean effect size on student performance. The weighted mean effect size of the treatment categories ranges from 0.50 to 1.80. Using the random-effect model, the inquiry-based learning (d = 1.783) has the largest mean effect size, followed by problem-based learning (d = 1.276) and cooperative learning (d = 1.268) which are close in effect values. Nearly of the same effect values shared by MMMR (manipulative, model and multiple representations) (d = 1.072), project-based learning (d = 1.035) and technology-aided instruction (1.017), then individualized instruction that still has positive effect level (d = 0.933). Combination learning showed to have a moderately positive effect on the performance of students.

Table 3
Meta-analysis of Qualified Studies on Academic Performance by Treatment Categories

Treatment Categories	N (Sample Size)	Mean Effect Size (Cohen's d)	Lower Limit	Upper Limit	Z Value	P Value
Combination Learning	130	0.687	0.332	1.041	3.797	0.000*
Cooperative Learning	594	1.268	0.612	1.924	3.79	0.000*
Individualized Instruction	484	0.933	0.118	1.748	2.245	0.025*
Inquiry-based Learning	828	1.783	1.118	2.449	5.253	0.000*
Manipulative, Models and Multiple Representations	537	1.072	0.587	1.557	4.333	0.000*
Problem-based Learning	257	1.276	0.186	2.365	2.295	0.022*
Project-based Learning	164	1.035	0.377	1.694	3.083	0.002*
Technology-aided Instruction	426	1.017	0.44	1.595	3.451	0.001*

*p<0.05

Figure 1 presents the forest plot of the mean effect size for treatment categories on academic performance. This provides a quick visual assessment of the individual studies included in the meta-analysis. It also presents the assessment of heterogeneity observed through categories and shows the overall treatment effect of the individual studies included (Israel & Richter, 2011). It can be observed that all the confidence intervals are judged to be significantly different from zero.

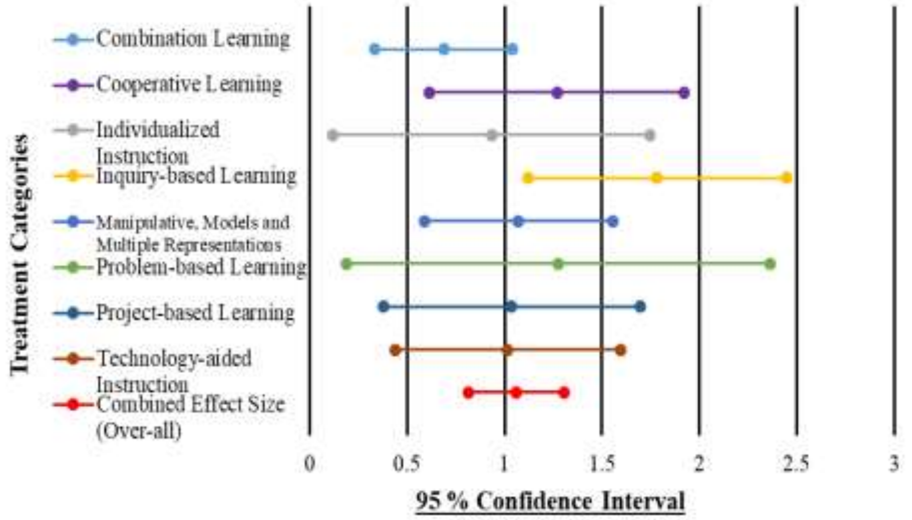

Figure 1
Forest Plot of Weighted Mean Effect Size at 95% Confidence Intervals for Treatment Categories on Academic Performance.

DISCUSSION

The presented results imply that in the field of chemistry, inquiry learning is considered a constructivist approach which is commonly studied teaching intervention concerning academic performance. Evident to this is the study of (Aktamis et al, 2016) who claimed that inquiry-based learning is a primary learning and teaching method for educating scientifically literate individuals. It is also accounted that graduate chemistry researchers engaged in the following methods: the use of models, symbols (abstract) and various representations, in small teams (groupings) and integrating technology, to explore their effects on secondary students. Several meta-analysis studies were conducted related to the effectiveness of such methods; use of technology, cooperative learning and manipulatives and how they impact student outcomes (Waxman et al, 2003; Capar & Tarim, 2015; Haas, 2005; Ugwuanyi, 2015). The outcome of this study implies that chemistry educators, teachers and students find it difficult to adapt and come up with the appropriate methodology that would really fit into the stream of these constructivist approaches; problem-based and project-based learning, hence, making it as the least studied area of research and practice in chemistry education in the Philippines. Besides, the very few quantities of multicultural education and combination learning presented would enlightened practitioners and researchers to pursue more of such teaching methods in promoting high-quality learning in chemistry. In such a case, multicultural education has only one study involved that denotes as weak and unreliable result, which in turn, not included in accounting for the meta-analysis.

One of the goals of the meta-analysis is obtaining a mean effect size of the over-all studies (Cavanaugh, 2002). Several factors like sample size and variance can influence the magnitude and direction of the effect size, the estimates of the effect sizes will vary among studies. In such a case, the effect size of the individual studies is imprecise and therefore can lead to an unstable finding when multiple small studies are utilized. Thus, weighing the standard error based on the sample size gives the best precision of the effect size estimates (Israel & Richter, 2011). The use of chemistry teaching methods is effective than the traditional or conventional method. The findings presented are supported by Jacobse & Harskamp (2012) who reported a statistically significant positive high effect on the use of instructional intervention on students' mathematics achievement. Also, Schroeder et al (2007) concluded a significant effect of teaching strategies (d= 0.67) on student achievement in science. The use of varied instructional methodologies helps students develop their cognitive and affective capabilities (Wu et al, 2001) and it also promotes critical thinking and long term conceptual understanding (Hussain & Ahktar, 2013).

As presented in Figure 1, it can be observed that there are some interesting results obtained from the study. First, it can be observed in the case of problem-based learning method, it has the widest range of interval and yet possessed a large over-all effect size. A wider confidence interval may be a function of a small sample size, as well as inaccuracy in the measurement. Hence, it is established that this category contained studies with small sample size. Obtaining such result most likely stems from a bias against non-significant findings included, it likely results in meta-analysis overestimating effect sizes (Levine et al, 2009). Second, the outcome of the inquiry-based learning contradicts with the interpretation of confidence interval, where there is a wider interval and possessed the largest effect size, which is supposed to have fine interval. This case indicates that the category contained individual studies with small sample size that eventually affect the interval values surrounding the effect size. Sample size is one of the factors identified that can influence the magnitude and direction of effect size (Israel & Richter, 2011). There is a negative correlation between sample size and effect sizes in studies included in meta-analysis (Levine et al, 2009). Mollon et al (2008) as cited by Israel & Richter (2011) stressed that when mentioning a similar scenario, the confidence intervals surrounding the over-all estimated effect size is still considered to be larger even when smaller studies are included in the meta-analysis. In such case, the quality of mean effect size value in each category is the primary basis in this study for interpretation. Thus, it is inferred that inquiry-based and problem-based learning has greater directive impact on student academic performance.

Within the collection of teaching methodology, the inquiry-based learning method that focuses on inquiry questioning, facilitated inquiry activities, guided discoveries, and inductive laboratory exercises seem to have the greatest impact on students' academic performance in chemistry. Activities in science classrooms could involve observations, questioning, investigating, predicting, explaining and communicating results (Caliksan, 2004). Yıldırım and Berberoglu (2012) as cited by Aktamis and Ozden (2016) stressed out that inquiry-based learning method had no significant effect on the eight-grade students' academic achievement and science process skills in regard to the unit of force and movement. However, Aktamis and Ozden (2016) reviewed a total of 19 studies on the effects of the inquiry-based learning method used in science education on student achievement and their conceptual comprehension. These studies were published between 2005 and 2015 and found that the inquiry-based learning method had significant effects on the students' academic achievement. Memorizing facts would not increase skills in students, but on having the freedom to explore and investigate through inquiry learning. Conventional teaching promotes rote memorization that does not develop or supports the development of students' problem solving and critical thinking skills (Maxwell et al, 2015). Chemistry has been an activity-oriented subject that requires learners to discover on their own with the help of the teacher that acts as the facilitator (Okwuduba & Okigbo, 2018). With its effectiveness and positive effects on students' academic achievement, inquiry-based teaching can be more involved in science education programs.

Problem-based learning (PBL), though was found to be one of the least studied categories, yet it presented a large effect on performance based on the analysis. The findings presented in comparison to traditional teaching, PBL's effect on academic achievement is relatively higher. This is in line with the findings of Okwuduba and Okigbo (2018) that "problem-based learning displayed a strong positive effect" towards achievement in chemistry. PBL is highly effective in developing all skills (Dagyar & Demirel, 2015). It directs students to do research, learn, discuss, and choose the best option among many solutions. Using this in the application process, it teaches students to research, teamwork, and observation from multi-perspective (Dagyar & Demirel, 2015).

It is then believed that students learn best when they are exposed along with their co-learners to work and achieve a certain task together. This method enable students to interact with one another and allows them to generate and exchange ideas freely. Grouping allows increases in instructional suitability and tutoring tailors instructional elements to each student (Walberg, 2003). The result on cooperative learning agrees with the results of Capar & Tarim (2015), who compiled scientific studies in Turkey and found a positive large effect (Cohen's d = 0.82) on academic achievement in science and mathematics. Cooperative learning was regarded as a more successful method than the traditional method with regards to achievement (Ayaz & Sekerci, 2015; Gul & Shehzad, 2015).

In terms of manipulative, model and multiple representations category, a recent meta-analysis mentioned by Cope (2015) that examined virtual manipulative obtained a moderate effect size of 0.44 as compared to other instructional treatments. In the same way, the meta-analysis conducted by Schroeder et al (2005) gave positive medium effect of manipulation strategies on science achievement in the United States. The positive effect size obtained in this study indicates that when using this teaching method in class, it can effectively enhance cognitive abilities of the students. Meaningful learning can be achieved if students are given opportunities to manipulate equipment and materials in an environment suitable to construct ideas and scientific concepts (Hofstein & Lunetta, 2013). This study suggests that teachers need to teach with visualization by using maps or graphs, videos, images, models, materials, etc. to increase student's conceptual understanding resulting to outstanding academic performance.

The use of technology continues its steady growth, both within and outside the classroom, its effect on academic performance becomes an increasingly important question to address. This method is rapidly emerging in a predominantly paradigm in the delivery of education in the society and has been observed that the use of technology is the best way to transfer knowledge from the teacher to the students (cited by Sobejana, 2016). Brown (2011) strongly support the negative effect and addressed the issues and challenges that threatens the leaning condition of students. It was also emphasized that common problems encountered during the process is that teachers often rely on the technology to teach students, rather than using the technology as an educational tool (Brown, 2011).

It is believed that if students are exposed in a learning environment where they can actively relate the teaching approach to their interests and needs and present knowledge and have an opportunity to experience various meaningful learning activities like collaborative scientific inquiry, under the guidance of an effective teacher, performance would be increased. Teachers can make learning relevant to students by presenting material in the context of real-world examples and problems wherein the students can explore learning through the use of technology, manipulatives, and various representations and students may be taken out of the classroom to engage into the world of real (authentic) experiences (Schroeder et al, 2007).

CONCLUSION AND IMPLICATIONS

In the last decade, nine different teaching methods have been implemented and evaluated in chemistry classrooms. The use of varied teaching methods showed a significant positive impact on academic performance. Incorporation of other avenues of learning via innovative teaching methods or strategies promotes a significant increase in the performance of the students. Academic performance can be enhanced if students are placed in an environment where they can actively connect chemistry instruction to previously learned scientific and chemical concepts and materials through constructivist (inquiry-based and problem-based) and collaborative learning methods. Moreover, the application of the innovative teaching methods/strategies supplemented with appropriate learning materials can enable more reality-based learning with possible achievement gains. The results of this study call for more empirical research studies particularly those that investigate the effectiveness of an instructional intervention towards student characteristics such as attitude, interest/motivation, learning styles and self-efficacy. The identification and implementation of methods that found to be effective in chemistry instruction is a key step in ensuring the success of students in their academic performance. It is also important to have more meta-analysis on science education, as in the Philippines there are only a few meta-analysis studies in this field. Chemistry teachers and educators should consider employing one of the various forms of pedagogies and methods that are effective in improving student performance and characteristics in chemistry. The results of the study try to define what teachers need to do more in order to provide quality instruction and new systems of assessing teacher's teaching in order to make necessary adjustments in their pedagogies. Knowledge of the effects of the factors on the students' learning as revealed in this research can provide necessary information which may be considered in future policy decisions and resource investments of science education stakeholders and policy makers.

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