Meta-analytic review of studies on the effectiveness of chemistry teaching methods on student transformation

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Abstract. In the hope to provide life-long and quality learning in chemistry education in the Philippines, quality of instruction must be guaranteed first. This calls for exploration and utilization of teaching methods that effectively promote student growth and learning success. In an effort to this, this study utilized the quantitative meta-analysis technique to integrate chemistry research findings that were conducted only in the Philippines covering the period 2005-2016. It aimed to investigate the effectiveness of teaching methodologies in secondary chemistry and their effects on student transformation consisting academic performance and student characteristics. A search procedure and broad literature review were executed in order to identify the potential and qualified chemistry studies from published and unpublished graduate theses, dissertations and journal articles. Meta-analysis was effectively and systematically carried out through study acquisition, study coding, determination of interrater reliability, establishing inclusion criteria, computation of effect size including mean and interpretation of analyses. The meta-analytic review revealed that during the last decade (2005-2016), nine different teaching methods have been implemented and evaluated in chemistry classrooms. It has been determined that incorporation of innovative methods significantly promote positive transformation of students as a whole in secondary chemistry. Moreover, findings provide evidence supporting that academic performance, attitude and motivation can be greatly enhanced if students are placed in an environment in which 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 method. The main implication of this research is that it generated empirical evidence supporting the effectiveness of innovative instruction in chemistry.

1. Introduction

Most reforms in chemistry education call for an emphasis on improving teaching quality and effectiveness. Research shows that the role of teachers have a profound effect on student growth and learning success. A chemistry teacher must be a catalyst of change. This change includes one’s ability to exceed the typical way of transforming students in the learning environment and to translate new understanding about inquiry and meaningful learning into actual habits of practice [4]. 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. 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 [5]. Various teaching methods/strategies have been introduced and adopted by chemistry educators and researchers as considering ways and means of
ensuring effective teaching and learning in school. However, questions about the effectiveness of teaching methods on student learning have consistently raised considerable interest in the thematic field of educational research [6]. Chemistry educators and researchers continually made efforts in conducting relevant studies that dealt with teaching-learning strategies, assessment on student outcomes, intellectual and nonintellectual 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 the 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 metaanalyze existing chemistry research findings geared to theory development to better inform teachers and educators. A research that deals with meta-analysis of chemistry education research findings geared to theory development is a pioneer across the available secondary chemistry educational researches in the country. Most of the educational researches conducted do not involve meta-analysis of findings rather empirical studies are abundant. Optimistically, the researcher sees 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 current status of chemistry education in the Philippines, it is really important to examine the type of methods/strategies used and how it effectively fits into the students’ needs and characteristics.

In light of the lack of previous meta-analyses on the issue, this study aims to integrate and meta-analyze chemistry education research findings covering the period 2005-2016. It also aims to describe and determine whether the use of teaching methodologies contribute significantly to student transformations (academic performance and characteristics) in secondary chemistry teaching-learning process based on the chemistry education research findings. This study addressed the following specific objectives:

1. To determine the over-all effect of the chemistry education studies qualified in the meta-analysis with regards to the use of teaching methods on student transformation.
2. To identify the teaching method categories that appear to have the largest effect size in relation to:
   - Academic Performance
   - Attitude
   - Learning Styles, Motivation, and Self-efficacy
   - Multiculturality

2. Methods

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 and potential moderators would be established. Moreover, this study employed a combination of qualitative and quantitative approaches to examine the relationship between teaching methodologies and the student transformations in chemistry education. Mixed methods research allows for the “opportunity to compensate for inherent method weaknesses, capitalize on inherent method strengths, and offset inevitable method biases” [7].

The qualitative aspect would involve the coding of chemistry education research findings or hyper-analysis mapping of meta-analysis results. On the other hand, studies of impact would be quantitatively synthesized using meta-analysis technique in order to produce a big picture of influence among variables. Research Locale Collection of chemistry education research findings of both published and unpublished studies were done nationwide in the Philippines to avoid publication bias. The search were systematically done in both private and state universities having graduate chemistry education and teaching program. The researcher personally conducted a broad search of possible pool of studies related to chemistry instruction throughout the Philippines and through or by online browsing.
2.1. Research Instruments

2.1.1. Study Qualifying Sheets. These sheets were developed for each cases of chemistry education that served as basis for qualifying the study during the pre-screening process. It contain the set of criteria specified in selecting the appropriate study.

2.1.2. Coding Sheets. The sheets were adapted [2] for each cases 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, 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.

2.1.3. Data lay-out Matrix. This matrix was used to summarize the information taken from the coding sheets and to facilitate the systematic analysis of science education research findings.

2.1.4. Mapping Matrices. These matrices were developed for 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. The researcher was responsible in facilitating the groupings of variables, in comparing the dataset of each outcome variable and in ranking of the effect size as to determine the categories of teaching methods (independent variables) that demonstrated as the most influencing factor to student transformations (i.e. student motivation, academic performance).

2.2. Data Gathering Procedures

2.2.1. Identification and Collection of Potential Studies. Empirical studies involving student transformation 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 student transformations including self-efficacy, learning styles, attitude, motivation, multiculturality and academic performance. A search procedure and broad literature review were executed by the researcher in order to identify the potential and qualified chemistry education studies from the published and unpublished graduate theses and dissertations. Moreover, a computerized search was also conducted 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.

2.2.2. Pre-Screening. Surface level screening was performed in each of the gathered chemistry education research in order to efficiently exclude a substantial part of studies that did not qualify on the inclusion criteria. In this manner, this was executed on the basis of reading title and abstracts. In the case where the essential study characteristics were not evident from the title and abstract, the full text would be consulted. Several rigorous criteria were employed for the inclusion of studies in this synthesis. The following criteria includes: 1) Studies should focused either on student self-efficacy, learning style, attitude, motivation, multiculturality and academic performance as resulting from the use of chemistry education teaching methods. 2) The study should be completed within 2005-2016. 3) The study should be conducted or carried out in the Philippines. 4) The study should be involved only in secondary chemistry academic domain. 5) The study should utilized the experimental or quasi-experimental research design. 6) The study report effect size (ES) or contain 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. The meta-analysis studied the relationships between the dependent variables and the potentially contributing independent variables [2]. In order 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 is student transformation, presented in six (6) different outcome variable namely; academic performance, self-efficacy, learning style, attitude, motivation and multicultural. Each of these were affected by the teaching method categories.

2.2.3. Coding Process. All studies gathered were coded by the researcher and a PhD level professional in science education. The coders performed the coding process separately using a coding scheme with the study features. The coding sheets were developed to delineate each study features based from the data extracted. Hence, the researcher gave a careful attention to the qualified studies as these served as the framework for analysis. Coding was done for each cases of chemistry education research findings. Each coding sheet was constantly refine as the synthesis proceeded. Both qualitative and quantitative information were coded using the sample coding sheet to permit comparison of findings across studies. The table for quantitative description of the different characteristics included in the case of the study were provided to the coders. Data extracted from each study are coded according to the features of the study.

2.2.4. Data Analysis. Study coding and data were compiled using a Microsoft Excel Spreadsheet 2013 in order to collect and organize the data. An excel form was be created to prompt for all needed features for each study and automatically save the information in a database from which analyses would be conducted. Alternatively, data were analyzed using the Comprehensive Metaanalysis Program/Software (Trial Version License). The following statistical analysis were conducted in this study. Meta-analysis – it provides a systematic method for accumulating and synthesizing statistical evidence from a variety of studies that address a common research question. The following statistical computation were executed in this meta-analysis:

- Compute Effect Sizes for Study
- Differentiate and determine weighted effect size for each study
- Test of Homogeneity
- Mean Effect Sizes
- Ranking of Mean
- Effect Size and Regression Analysis

3. Results and Discussion

3.1. Meta-analysis for All Studies

One of the goals of the meta-analysis is obtaining a mean effect size of the over-all studies [3]. Using the random-effects model, the computed mean effect size for the 67 studies is 0.982, considered as a large positive result as presented in Table 1. 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 case the effect size of the individual studies may somewhat imprecise and therefore can lead to an unstable finding when multiple small studies are utilized. Thus, weighing of the standard error based on the sample size gives the best precision of the effect size estimates [8]. The standard error of the weighted mean effects is 0.089. Hence, this over-all result can be reflected as a strong high level. At a confidence level of 0.05, the 95% confidence limit was determined. In this manner, the confidence limits were 0.806 and 1.157. Confidence intervals of continuous measure that include zero represent non-significant results [8]. Since the interval never reaches at zero, the null hypothesis that the population effect size is zero can be rejected. The use of chemistry teaching methods is considered effective than the traditional or conventional method.

| Table 1. Metaanalysis for all studies. |
|----------------------------------------|
| Over-all Effects | Mean ES | Mean SE | Lower Limit | Upper Limit | Z Value | Over-all P Value |
| 67 Studies | 0.982 | 0.089 | 0.806 | 1.157 | 10.970 | 0.000 |
The findings presented agree with [9] who reported that their metaanalysis of the effect of instructional intervention on students’ mathematics achievement indicated a statistically significant positive high effect (Cohen’s d = 0.58). In the study of [12], it also concluded a significant effect of teaching strategies (d= 0.67) on student achievement in science.

3.2. Meta-analysis for Studies Classified by Treatment Categories
The 67 chemistry education research studies describe the effects of the nine identified teaching method (treatment) categories on student transformation. Student transformation refers to the student characteristics like self-efficacy, attitude, learning style, multiculturality and academic performance in chemistry teaching-learning process. It is a common process of assimilative learning, the type of learning that takes place when students simply acquire new information/knowledge that can easily fit into their pre-existing knowledge structures [11]. With the same meta-analysis procedure, each study was assigned by an effect size, and a mean effect size was determined for each treatment categories. This also permits the ranking of teaching method categories according to their effects on each dependent variable.

3.3. Effects of Treatment Categories on Academic Performance
Table 2 shows the metaanalysis results for the studies investigating the effects of each treatment category tailored to students’ academic performance. As seen in the summary 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).

Table 2. Frequency distribution of students on academic performance by treatment categories.

| Treatment Categories                    | N  (No. of Studies) | Percentage |
|----------------------------------------|---------------------|------------|
| Combination of Learning                | 2                   | 3.92       |
| Cooperative Learning                   | 9                   | 17.65      |
| Individualized Instruction             | 15                  | 9.80       |
| Inquiry-based Learning                 | 11                  | 21.57      |
| Manipulative, Model and Multiple       | 10                  | 19.61      |
| Representations                        |                     |            |
| Multicultural Education                | 1                   | 1.96       |
| Problem-Based Learning                 | 4                   | 7.84       |
| Project-Based learning                 | 3                   | 5.88       |
| Technology-Aided Instruction           | 6                   | 11.7       |
| TOTAL                                  | 51                  | 100.00     |

The presented results implies that in the field of chemistry, inquiry learning considered a constructivist approach is the commonly studied teaching intervention with regards to academic performance. It can also be 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, as to explore their effectiveness on secondary students. In addition, the very few quantity of multicultural education and combination learning presented in this study would be an enlightening for practitioners and researchers to pursue more of such teaching methods in promoting high quality learning in chemistry. In such case, multicultural education has only one study involved which denotes as weak and unreliable result, which in turn, not included in accounting for the meta-analysis as presented in succeeding part.
Table 3. Meta-analysis of qualified studies on academic performance by treatment categories.

| Treatment Categories                          | Mean Effect Size | Lower Limit | Upper Limit | Z Value | P Value |
|-----------------------------------------------|------------------|-------------|-------------|---------|---------|
| Combination of Learning                       | 0.687            | 0.332       | 1.041       | 3.797   | 0.000   |
| Cooperative Learning                          | 1.268            | 0.612       | 1.924       | 3.79    | 0.000   |
| Individualized Instruction                   | 0.933            | 0.118       | 1.748       | 2.245   | 0.025   |
| Inquiry-based Learning                       | 1.783            | 1.118       | 2.449       | 5.253   | 0.000   |
| Manipulative, Model and Multiple Representations | 1.072          | 0.587       | 1.557       | 4.333   | 0.000   |
| Problem-Based Learning                       | 1.276            | 0.186       | 2.365       | 2.295   | 0.022   |
| Project-Based learning                       | 1.035            | 0.377       | 1.694       | 3.083   | 0.002   |
| Technology-aided Instruction                | 1.017            | 0.44        | 1.595       | 3.451   | 0.001   |

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 representation) (d = 1.072), project-based learning (d = 1.035) and technology-aided instruction (1.017), then individualized instruction that still have positive effect level (d = 0.933). Combination learning showed to have moderate positive effect on the performance of students. The 95% confidence intervals for the treatment categories are presented in Table 5. It can be clearly noticed that all the confidence intervals are judged to be significantly different from zero. Confidence interval lend insight into the precision of the treatment estimates included in the studies. Conversely, a wider confidence interval indicates less precise estimates and coupled with a small sample size, can lead to imprecision in measurement [8]. Within the collection of teaching methodology, the inquiry-based learning method such that focus on inquiry questioning, facilitated inquiry activities, guided discoveries and inductive laboratory exercises seem to have the greatest impact on students’ academic performance in chemistry. As emphasized by Maxwell, Lambeth and Cox (2015), activities in science classrooms could involve observations, questioning, investigating, predicting, explaining and communicating results. 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.

3.4. Effects of Treatment Categories on Attitude
A total of twelve (12) studies were reviewed and made it into the meta-analysis in relation with the use of different teaching methodologies in secondary chemistry and as it influenced students’ attitude. Table 4 presents the meta-analysis outcome of this study. It can be observed that cooperative learning (n = 3) is the top most method being studied on attitude, followed by project-based learning (n = 2) and individualized instruction (n = 2). The rest of the identified methods except combination learning, only a single study was qualified in the analysis based on the given inclusion criteria. However, no studies were reviewed on combination learning. The findings show that there are still very few available empirical studies conducted in the Philippines that centers the effects on student attitude in the chemistry teaching-learning process.
Table 4. Frequency distribution of studies on attitude by treatment categories.

| Treatment Categories                  | N (No. of Studies) | Percentage |
|---------------------------------------|--------------------|------------|
| Combination of Learning               | 0                  | 0          |
| Cooperative Learning                  | 0                  | 27.27      |
| Individualized Instruction            | 2                  | 18.18      |
| Inquiry-based Learning                | 1                  | 9.09       |
| Manipulative, Model and               | 1                  | 9.09       |
| Multiple Representations              |                    |            |
| Multicultural Education               | 1                  | 9.09       |
| Problem-Based Learning                | 1                  | 9.09       |
| Project-Based learning                | 2                  | 18.18      |
| Technology-Aided Instruction          | 1                  | 9.09       |
| Total Studies                         | 12                 | 100        |

The main purpose of meta-analysis is to increase precision of a conclusion which the single studies were not able to cater due to imprecision. However, as presented in Table 5, it can be observed that treatment categories in the following: inquiry-based learning, manipulative, models and multiple representations, multicultural education, problem-based learning and technology-aided instruction, possessed of only a single study with no multiple results. Thus, these categories were considered to be imprecise and not interpretable. This implies that more studies are still needed in these teaching method categories in order to derive to a definite conclusion. The findings disclosed that there are still very few available empirical studies conducted in the Philippines that explores the effectiveness of different teaching methods/strategies on student attitude in the chemistry teaching-learning process. Examining the meta-analysis results as shown in Table 4, significant mean effect sizes were observed in the following teaching methods based upon the use of random-effects model; cooperative learning (d = 0.500), project-based learning (d = 0.452), and individualized instruction (d = 0.388). Each of the obtained mean effect sizes corresponds to be small which denotes that these treatment categories to have significant effects toward the given outcome variable. In the same way, it can be deduced that they are effective yet in a minimal manner as compared to traditional teaching.

Table 5. Meta-analysis for qualified studies on attitude by treatment categories.

| Treatment Categories                  | Mean Effect | Lower Limit | Upper Limit | Z Value | P Value |
|---------------------------------------|-------------|-------------|-------------|---------|---------|
| Cooperative Learning                  | 0.500       | 0.311       | 0.690       | 5.18    | 0.000   |
| Individualized Instruction            | 0.388       | 0.171       | 0.606       | 3.507   | 0.000   |
| Project-Based Learning                | 0.452       | 0.166       | 0.739       | 3.091   | 0.002   |

Cooperative learning revealed to have largest significant effect size on student attitude followed by project-based learning and individualized instruction. Cooperative learning can be a useful tool to help develop a positive attitude toward learning [10]. Several studies affirm that cooperative method was better than traditional method in terms of stimulating positive attitude [1]. However, the very small effect size observed in project based learning and individualized instruction denotes small effect based on the Cohen’s interpretation, presenting a minimal impact on students’ attitude. The lower effects of constructivist method such as inquiry-based, problem and project-based learning on attitude outcome is most likely due to the lack of requisite materials needed for carrying out investigations in a chemistry classroom. Since this method mainly focused on questioning, investigation and problem-solving that involved hands-on manipulation and required critical and creative thinking skills, this
probably give students the negative impact and perceiving it to be difficult, less enjoyable and inconvenient on their part.

3.5. Effects of Treatment Categories on Learning Styles, Motivation, Self-efficacy

In the efficacy of teaching methods on other dependent variables, learning styles, motivation and self-efficacy, four (4) studies were qualified in the meta-analysis. According to random-effects model as presented in Table 6, only cooperative learning displayed a significant large effect (d = 0.860) on students’ motivation. However, inquiry-based learning did not exhibit any significant effect on motivation (d = 0.080). Moreover, no significant effect were identified on learning styles and self-efficacy with respect to the use of inquiry-based learning and cooperative learning. In this meta-analysis, a single study was observed however it has multiple findings presented. These findings indicate that the cooperative learning method was found to have a significant impact than the traditional method in terms of an increasingly positive interest/motivation towards learning chemistry. It can be addressed based on the findings that cooperative learning method was found to have a significant impact than the traditional method in terms of an increasingly positive interest/motivation towards learning chemistry. This kind of teaching method is relevant in the chemistry instruction because students learn to work as part of a team to with various tasks and solve problems. In today’s world, working in teams is encourage to solve complex problems, so it is imperative that students should be taught and be exposed on how to be an effective member of a team (Quinn, 2006).

Table 6. Meta-analysis for qualified studies on learning styles, motivation and self-efficacy by treatment categories.

| Treatment Categories | N (No. of Studies) | Mean Effect Size | Mean Standard Error | Lower Limit | Upper Limit | Z Value |
|----------------------|--------------------|------------------|---------------------|-------------|-------------|---------|
| Learning Styles      |                    |                  |                     |             |             |         |
| Inquiry-based Learning | 1                 | 0.199            | 0.176               | -0.146      | 0.544       | 1.130   |
| Motivation           |                    |                  |                     |             |             |         |
| Cooperative Learning | 1                 | 0.860            | 0.241               | 0.388       | 1.332       | 3.571   |
| Inquiry-based Learning | 1                | 0.080            | 0.176               | -0.265      | 0.425       | 0.454   |
| Self-efficacy        |                    |                  |                     |             |             |         |
| Cooperative Learning | 1                 | 0.041            | 0.203               | -0.356      | 0.438       | 0.202   |

3.6. Effect of Treatment Categories on Multiculturality

No studies were able to qualify for the meta-analysis on student multiculturality. This study can provide a clear information that there is a need to direct the research focus on student multicultural and to further examine how they can be influenced or changed by the use of a suitable instruction.

4. Conclusion and Recommendations

As a result of this study, it has been determined that teaching methodologies included in the meta-analysis exhibited an over-all large effect size (d = 0.982) on student transformation as a whole. Constructivist teaching approach (inquiry-based and problem-based learning) and cooperative learning were among the studied teaching method categories that exhibited a significant strong impact on students’ academic performance as compared to the conventional teaching. In terms of student
characteristics, cooperative learning displayed significant effect size on both variables; attitude and motivation. For the purpose of this study, this calls for more empirical research studies particularly those that investigates the effectiveness of an instructional intervention towards student characteristics such as attitude, interest/motivation, learning styles, self-efficacy and multiculturality. It is also important to have more metaanalysis on science education, as in the Philippines there are only a few meta-analysis studies in this field.

It is then recommended based from the findings of this study, chemistry teachers and educators should consider employing one of the various forms of pedagogies and methods that have been shown to be effective in improving student performance and characteristics in chemistry. Also, this study can be a benchmark to venture other meta-analysis studies examining effects of various methods applied in teaching other discipline of science; physics, biology and general science.

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