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The Taxonomy of Predict-Observe-Explain (POE) as a Teaching Strategy and Thinking Process of Chemistry Stakeholders

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Abstract

Predict-observe-explain (POE) is a strategy being used during scientific investigations and experiments. However, POE-related studies mainly focused on its validity and reliability as a teaching strategy in classrooms. Thus, this paper extends the context of POE discussion not only as a teaching strategy but also as science process skills, and as cognitive thinking skills in performing experiments and answering scientific inquiries among chemistry stakeholders: students, teachers, and chemists. The study sees POE as a way to develop critical thinking and builds the skills needed for further academic and professional endeavors in the different fields of science. Through a constructivist grounded theory methodology using focus group discussions for students and in-depth interviews with the teachers and chemists, the study: described how students, teachers, and chemists exemplified POE strategy in terms of its process, and identified mutual patterns of POE process from the chemistry stakeholders. The study revealed that: student POE taxonomy is focused on basic processes and structures of POE; teacher POE taxonomy is a guide in their lesson planning; and chemist POE taxonomy is based on local and international compliance during experimentation. Therefore, POE is a science process skill for chemistry stakeholders where the POE taxonomy used by the chemistry stakeholders are different based on experiences, needs, and context.

Introduction

According to Haysom & Bowen (2012), one of the prevalent pedagogical strategies in teaching science is the Predict-Observe-Explain (POE). In Perver's study (2015), the use of POE improved not just the students' prediction, observation, and explanation abilities in science, but also their ability to adapt their prior knowledge to the learning scenario. Considering the foregoing discussions about POE, Vadapally (2014) recommended further understanding of the pattern of student achievement in chemistry using POE by factoring the nature of students' thinking skills and the teacher's instructional strategies, as well as creating a learning environment where students are actively thinking and learning. To address this gap, the study extended the discussion of POE not only as pedagogical strategy but also as a thinking and process skill of chemistry stakeholders (students, teachers, and chemistry teachers) through their conduct of experimentation using POE. With this, the study aimed to map out the taxonomy of each stakeholder and establish a POE taxonomy based on the demonstrated mutual patterns.

Science Process Skills and Thinking Skills in Chemistry

Cognitive thinking is the use of mental activities and skills to perform tasks such as learning, reasoning, understanding, remembering, paying attention, and more ("What are Cognitive Skills?," 2021). Cognitive thinking is a foundational skill that allows man to function as a member of society (Elder & Paul, 2010), and transferable abilities in various science disciplines and are reflective of the behavior of scientists (Padilla, 1990). Moreover, Neumann (2010) enumerated that the cognitive thinking skills are: prediction, modeling, experimentation, evaluation, diagnosis, planning, causation, judgment, influence, teamwork, negotiation, and describing. Therefore, cognitive thinking skills and science process skills interweave scientific content and skills because they put structure and process on how one thinks.

Science Process Skills in Chemistry Teaching

The low-quality education is mostly being attributed to a lack of effective instructional materials because of the government's insufficient budget allocation (Gernale, Arañes, & Duad, 2015), mismatched teaching strategies that do not meet the needs of the learners in meeting global standards (Kibirige, Osodo, & Tlala, 2014), and under-qualified science teachers (Mthembu, 2001). In the course of educational development, science teaching dramatically metamorphosed in terms of content and pedagogical intervention (Gernale, et al., 2015; Kibirige, et al., 2014). The development is contributed to the engagement of measuring student achievements and attitudes toward science learning, however, science teachers are challenged by their personal self-concepts in the content and manner to teach the subject. This negative conception of science teachers is echoed by Gernale, et al. (2015), that teachers do not like to teach science, and they express a lack of confidence in their ability to teach science. Through these attitudes to science teaching, teachers affect students' attitude toward science which is why setting proper attitudes towards the subject is necessary. The aforementioned factors lead to the students' poor understanding of science concepts. Thus, improving the quality of education using a learner-centered approach is a global direction (Kibirige, et al., 2014). The primary concern of the change is to adapt to the ever-changing needs of the learners in meeting the present standards through the development of critical thinking skills.

As students' prior knowledge ideas, beliefs and attitudes affect how they interpret new observations and accommodate new knowledge in the science classroom; what is learned is not always what the teacher intended. One way that teachers can address this issue is to incorporate strategies into their teaching repertoires that overtly provide insights into students' understanding of the phenomenon being examined (Treagust, 1988, p. 68). Innovation in teaching strategies is important in addressing the need of the students to learn science and do a scientific inquiry effectively. Combined with 21st-century learning skills, stakeholders can expect great achievement in science, especially in the conceptual understanding of chemistry. According to Hanover Research Analysis, ("A Crosswalk of 21st Century Skills," 2011) one important 21st-century skill is critical thinking where the abilities to predict, observe, and explain are being used in exercising one's critical thinking skills. Science, as a discipline, anchored these contemporary critical thinking skills to six basic process skills namely: observation, communication, classification, measurement, inference, and prediction.

Science process skills and cognitive thinking skills are being developed and enhanced in the science curriculum using three major cognitive processes that are evidently being practiced by students during experiment and any scientific investigation: prediction, observation, and explanation; "[s]tudents concentrate on following recipes, collecting and recording data in the laboratory guide which is including list of tasks for students in the environment" (Şeşen & Mutlu, 2016, p. 186). Taking inspiration from these common thinking skills, Champagne, Klopfer, & Anderson (1979) tried to probe the thinking of first-year physics students at the University of Pittsburg and designed a strategy called "Demonstrate-Observe-Explain." Then, White and Gunstone (1992) revisited and enhanced the strategy and introduced a constructivist teaching strategy as "Predict-Observe-Explain." This consists of three tasks such as prediction, the phase that helps students construct their own predictions in given tasks; observation, the part when students describe and note details of comments during a demonstration of an experiment or investigation; and explanation, the segment that aids students to resolve any discrepancy in their own prediction and observation.

Mthembu (2001) showed that teachers can use a constructivist strategy such as POE in designing learning activities because it considers the students' point of view which is aligned with the constructivist theory of including the prior knowledge of the students in the equation of learning acquisition.Furthermore, the POE strategy also embraces the idea that aside from knowledge, feelings are important to the acquisition of knowledge which is why Gernale et al. (2015) included humanistic learning theory as the coinciding theoretical framework of POE.In the process of POE implementation, explanation is part of communication in science process skills. POE is observed as the set of common skills being practiced by chemistry students because by just reading the procedures indicated on the laboratory activity sheet before the actual experiment, the student's mind starts to work by predicting the outcome of the experiment using his/her prior knowledge or schema (Freedman, 1997; Hofstein & Lunetta, 1982; Thompson & Soyibo, 2002).

Although there are several skills that students need to use to accomplish the experiment, observation is one of the most important thinking skills to study since doing a quality observation means gathering excellent data. Besides students' having opportunities in a laboratory environment, it has been discussed that students can enhance their conceptual understanding and positive attitudes if laboratory activities are carried out in an appropriate manner. In a traditionally cookbook laboratory setting, students only follow the directions given and the experimental procedure. Students concentrate on following recipes, collecting and recording data in the laboratory guide which is including list of tasks for students in the environment (Şeşen & Mutlu, 2016, p.186). Lastly, to make sense of the data gathered, explanation is another skill that needs to be scrutinized as this gives the essence of why an experiment needs to be done.

POE is an powerful strategy, however, it is revealed that in POE strategy can lead to extreme results, learners can either become dissatisfied with their existing knowledge or find the new knowledge plausible, intelligible, and fruitful or accommodate, assimilate, or reject the new knowledge (Kibirige, et al. 2014).Students' existing ideas are often strongly held; they may undergo instruction in a particular science topic yet, they do not change their original ideas pertaining to the topic even if these ideas are in conflict with the scientific topic they are taught." (Mthembu, 2001, p. 7). Thus, the independence given to the students by POE in processing information at some point creates the dilemma of unsuccessful processing of knowledge. It emphasizes that the teacher must be able to assist the students to reconcile the inconsistency between the students' predictions and observations by encouraging students to take charge of their learning and for the curriculum makers to improve the learning materials suitable for POE strategy implementation.

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Kibirige, et al. (2014) revealed that despite the considerable increase of student competency in learning about dissolved salts where they overcame initial misconceptions about the concept, the study also identified two new misconceptions: salt dissolves in water when it is in 'fine' grains, and sodium chloride is not an ionic compound. Furthermore, considering POE as an e-teaching strategy, Dalziel (2010) articulated that the two types of POE: the synchronous (in real-time) in a computer lab in school contexts, and asynchronous uses between two face to face classes have disadvantages. [If it is synchronous,] online discussion ends when lab session ends, it may limit the chances of students to explore ideas; and [if it is asynchronous,] rich discussion in the explanation phase needs students to reach this stage at the same time and log in regularly, otherwise, it loses momentum" (Dalziel, 2010 p. 21).

It only means that, when the attention of students was lost from the instructions and information, the process collapsed, so the process needs intricacy and delicacy. Prediction, observation, and explanation are now used as science process skills. Indeed, POE effectively addresses the needs of the learners in science. Yet, aside from bridging learning gaps, the researchers forward to include how POE is aligned to the existing established competency standards from different government agencies.

POE Teaching Strategy

The curriculum of basic education forges creative and critical learners. In Southeast Asia, Indonesia's 2013 curriculum aims to make individuals and citizens who are creative, critical, and functional members of the society (Syamsiana, Suyatno & Taufikurohmag, 2018); Laos's revision of their education in 2008 intends to provide necessary knowledge for continuing education or profession (Khanthavy & Yuenyong, 2009); the Philippines' K-12 curriculum targets to offer concepts and skills mastery, lifelong learners development, tertiary education preparation, and middle-level skills development (Official Gazette of the Republic of the Philippines, n.d.). Common to these curricular aspirations is the capability of educational systems to mold learners to be competent in terms of knowledge and skills; to help develop all-rounded learners who can actively participate in the economic reconstruction of the society (Sreerekha, Arun Raj & Swapna, 2016); and to depict the sentiment of modernizing the society by developing Science and Technology. The curricular paradigm is to focus on significant and long-term change as the educational energy is to go beyond students' knowledge (Sales, Avilla & Camacho, 2015).

High levels of technological and high proficiency of scientific understanding are important curricular considerations, which become the advantages of academic enrichment. The scientific-oriented thinking process needs to use scientific concepts that will explain the observation to further reinforce new knowledge (Teerasong, Chantore, Ruenwongsa, & Nacapricha, 2010). Through these efforts of enhancing and innovating pedagogy that adapts to the present needs of society and learners, POE teaching strategy responds to this call. It is effective in improving conceptual understanding based on students' cognitive development (Syamsiana et al., 2018; Baltaci & Yildiz, 2018). POE highly demands active and creative participation from students during the learning process because the POE allows students to explore initial ideas, generate dialogue between students and teacher, investigate concepts, and awaken curiosity (Irfan, 2017).

POE strategy enhances the understanding of scientific ideas in two ways: common sense interpretation where learners use sensed impressions and form interconnecting concepts and interpretation to explain the world around them ("Using POE Sequences," n.d.). Through experimentation enforced by POE, a problem is presented in which learners are asked to provide possibilities, probe the truth by experimentation, and explain the phenomenon (Irfan, 2017; Hilario, 2015). Hence, POE allows learners to explore prior knowledge and actively navigate learning during the learning process.The first phase is prediction. It uncovers students' predictions and their reasons for making these about the phenomenon being examined (Sreerekha et al., 2016; Costu, Ayns, & Nïaz, 2012; Syamsiana et al., 2018). The primary concern is to allow students to elaborate on how they make sense of the situation. According to Hilario (2015), this phase is done by students initially listing all their predictions and then selecting the most sensible and reasonable prediction. Cinici and Demir (2013) identified prediction as to when students become dissatisfied with their present knowledge about the phenomena. This elicitation of students' ideas is important for the teachers and the students in building academic rapport; insights into how students think, while students will be conscious of their thinking ("Using POE Sequences," n.d.); neurons communicate with each other and create an understanding (Syamsiana et al., 2018); and recognize that nonscientific conceptions have potential impacts on learning (Cinici & Demir, 2013). Thus, prediction becomes a cognitive structure that is placed when prior information is invested in connection to the new information.

The second phase is observation. Students describe, build, and discover new concepts based on what they have seen in the demonstration-observation practice, and read in books (Sreerekha et al., 2016; Costu et al., 2012; Syamsiana et al., 2018). They record observations and repeat the activity when necessary to identify if their prediction is correct or otherwise (Hilario, 2015). In particular, students are trying to verify the intelligibility, awareness of the new concept and plausibility, and capacity of the new concept to answer the problem (Cinici & Demir, 2013). They perform the experimentation in groups to help their groupmates who find challenges in understanding the concept. According to John, there are two levels of cognitive development: the level of actual development, the ability to independently finish tasks; and the level of potential development, the ability to dependently finish tasks with peers (as cited in Syiamsiana, 2018). If there is a demonstration of the experiment, teachers are encouraged to let students help out and write their observations ("Using POE Sequences," n.d.).

The third phase is explanation. Students must reconcile the conflict between prediction and observation to explain the event (Sreerekha et al., 2016; Costu et al., 2012; Syamsiana et al., 2018), and deconstruct the process that happened (Khanthavy & Yuenyong, 2019). They detail the alterations in the variables and point out discrepancies between what was initially predicted and what occurred (Hilario, 2015); these student explanations are either field experience or research findings; the former focuses on the conducted field testing, the latter traces resemblances between the experience and findings ("Using POE Sequences," n.d.).

On one hand, for students, this phase is a reconfiguration of sensing the world, which is also called accommodation, a process that involves replacement or reorganization of learners' concepts to more scientific ones (Cinici & Demir, 2013). Perceptions are questioned and tested by an environment that allows exploration not only by himself but also with others. This is fruitfulness, the final condition of conceptual change (Cinici & Demir, 2013). On the other hand, for teachers, this phase is the scientific explanation established by scientists. The inclusion of information from students' short and long-term memory is necessary to organize their self-conceptual understanding (Syamsiana et al., 2018).

Methods

This study aimed to create a taxonomy of POE as thinking strategy and process skill that is demonstrated by chemistry stakeholders (students, chemistry teachers, and chemists). Thus, this study employed qualitative research specifically the constructivist grounded theory by Charmaz (2006) for researchers accounted experiences of the chemistry stakeholders in their use of the POE strategy in performing experiments through a series in-depth interviews, class observations, focus group discussions, and document analyses. It is anchored to ontological philosophical assumption because of the multiple natures of POE which were shown in the responses of the chemistry stakeholders, and the scaffolding instruction of POE tasks. The POE taxonomy is established by using variation purposive sampling technique for the 24 chemistry stakeholders:

The eight chemist-respondents are working in different local and international industry institutions. All chemist-respondents passed the licensure examination facilitated by the Professional Regulation Commission in the Philippines; a graduate of BS Chemistry degree; have experienced or is still working in the Research and Development (R&D) Department; and have been working for a minimum of five years in the science laboratory. The gender and age of the chemists did not matter in this study. The chosen chemist-respondents are products of Philippine chemistry education who are using POE in doing experiments in their workplace. They were selected to see the perspective of chemists in their use of cognitive and process skills, as well as protocols in conducting experiments.

The eight chemistry teachers are junior and senior high school levels in Antipolo and in Metro Manila, Philippines. These chemistry teachers were included in the study should be at least a graduate of Bachelor of Secondary Education major in Chemistry or their specialization is in the allied science programs with an emphasis in chemistry and have been teaching chemistry for at least five years in basic education. The eight student-respondents in this research came from Antipolo City Senior High School (ACSHS) that offers Science, Technology, and Mathematics (STEM) strand, where General Chemistry 1 & 2 subjects are being offered. The STEM classes in ACSHS were chosen by the researcher to implement the POE teaching strategy during chemistry laboratory classes. The criteria in choosing the student-respondents are mentioned below.

First, the General Point Average (GPA) range in Chemistry subject should be 75%-85% (below average to average) and 86%-99% (average to above average). Second, an equal number of student-participants, based on their GPAs, were selected from STEM 1201 and STEM 1202 classes for the focus group discussions. Four students from each section were selected by the researcher to have good interactions and discussions during the FGDs. Third, voluntary participation of the student-respondents in the study was observed. Lastly, gender identity was not considered in choosing the student-respondents. The sources of information in this study were the chemistry stakeholders' interpretation of POE based on their personal and professional experiences through the data from interview questions, observation notes, laboratory reports, and focus group discussions.The interview questions for chemists and teachers and the focus group discussion (FGD) questions for students were general and open-ended. They probed their experiences on how they use POE as science process skills and as a strategy in doing experiments. These questions are based on fundamental psychological and educational processes (Charmaz, 2006). Moreover, the questions are attentive to the respondents' different working conditions, the respondents' implicit and explicit conceptualization of perspectives, and their meaning-making of certain ideas or concepts.

The focus group discussion has fifteen guide questions that were sequenced in order of prediction, observation, and explanation. The questions determined the experiences of the students in the six laboratory activities/experiments that employed the POE teaching strategy. Another research tool used in this study was the lesson plans for the laboratory experiments using POE teaching strategy. The lesson plans in the General Chemistry 2 consisted of POE tasks that were adapted from the teaching guides of TeachTogether for each major topic that use POE strategy for the laboratory experiments: Energy of Solution Formation, Chemical Kinetics, Chemical Equilibrium, Electrochemistry: Oxidation-reduction Reactions, Thermochemistry: Energy Changes in Chemical Reactions, and Strength of Acids and Bases. The lesson plans were provided by the researcher to be implemented by the chemistry teacher in ACSHS. The topics covered the fourth quarter of General Chemistry 2 as specified in the DepEd Curriculum Guide. All provided lesson plans contained experiments using POE teaching strategy and followed the comments and suggestions validated by the experts.

Results and Discussion

Taxonomy of the POE Strategy

This study presents the taxonomy of the POE strategy. The said taxonomy highlights the levels of difficulty of the stakeholders' prediction, observation, and explanation strategy. Based on the extracted data, there are a handful of commonalities in typology, process, and structure among all chemistry stakeholders. The possible reason is that they have different levels of academic and professional careers which significantly affect the breadth of their understanding and utilization of POE. Thus, an individual Taxonomy of POE strategy for each chemistry stakeholder is detailed and presented. Figure 1 shows the students' taxonomy of POE from the lowest level of process and structure based on the lowest to the highest level. Most of the competencies present in the students' taxonomy refer to basic processes and structures of POE. The POE taxonomy of students shows that it focuses on the progress of what they attained and conscious of what they can still aim for; and guide students for independent learning since students can particularly point out what particular type, process, and structure of POE are needed in order to properly understand the experiment. The teachers' POE taxonomy as shown in Figure 2 is a combination of competencies referring to the beginner up to the proficient level of conducting the experiment. Their responses in the interview were derived from their experiences in doing the experiment in school laboratories where they teach.

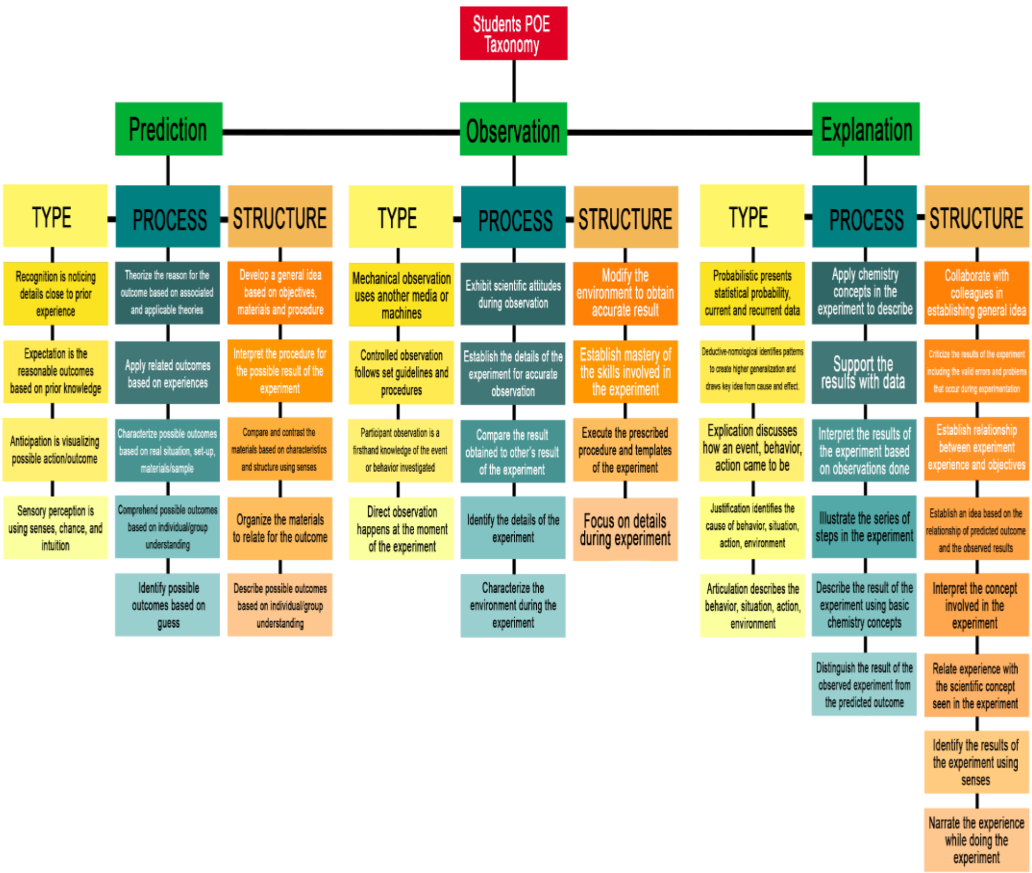

Figure 1. Hierarchical POE Taxonomy based on Students

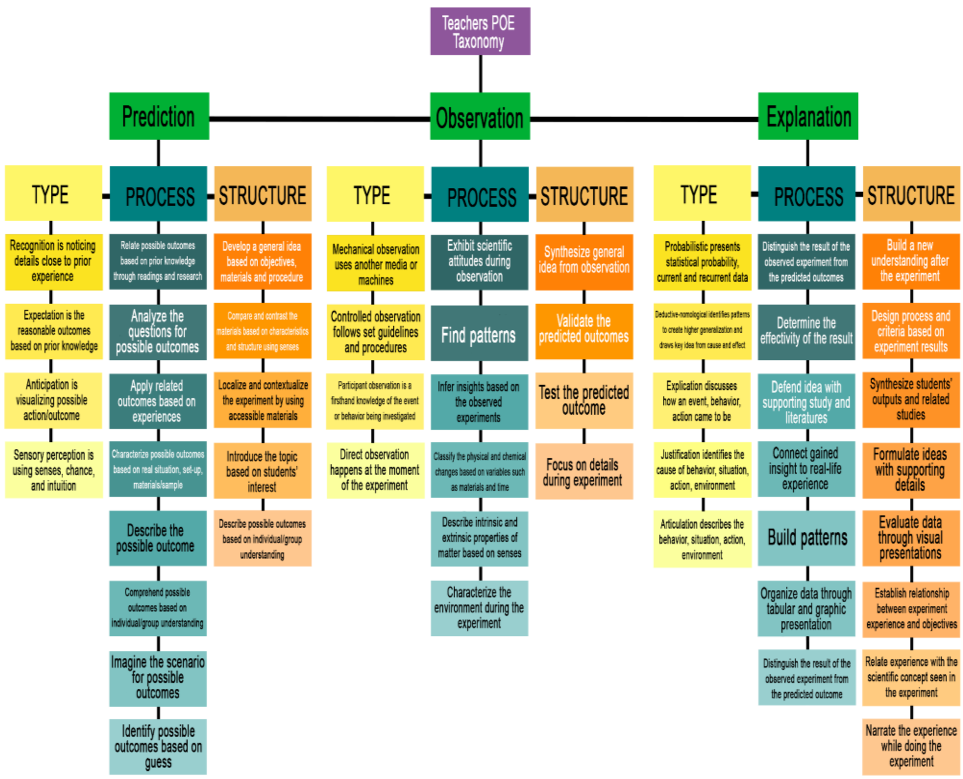

Figure 2. Hierarchical POE Taxonomy based on Teachers

The implication of the taxonomy for teachers is to guide them during lesson planning. The POE taxonomy can specifically give teachers proper tools for implementing experiment that will focus on how the learning outcomes can be attained. Knowing the complex nature of POE taxonomy, teachers can now identify what specific type, process, and structure of POE needs more attention and emphasis in teaching students.

In Figure 3, the chemists' POE taxonomy shows few competencies in the beginner level of POE competencies. This taxonomy illustrates competencies of POE as high proficiency level because chemists are licensed professionals who conduct experiments. Their processes and structures of POE also show highly technical processes and adhere to the local and international standard operating procedures in performing experiments. Their POE competencies show the rigor of doing the experiments from analysis, data interpretation, and establishment of conclusions. For instance, the observation process of the chemist is to verify the results of the experiment, then justify the predictions made, and finally validate the results based on standards and literature. The implication of the taxonomy to chemists is to vary processes based on the common practices in the field. Since chemists predict using results from journals, innovation in the industry can be attained by using different POE processes.

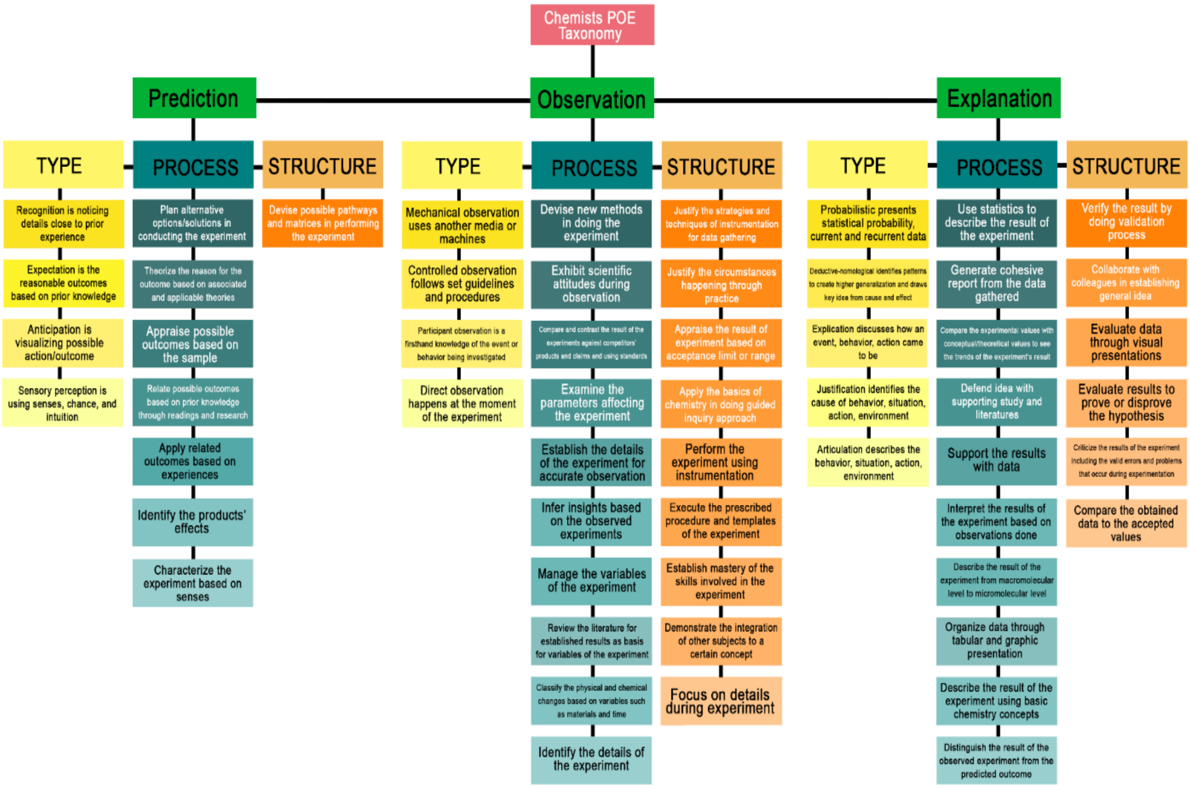

Figure 3. Hierarchical POE Taxonomy based on Chemists

Hence, the stakeholders' individual taxonomies give proper reference in using the predict-observe-explain strategy because the identified competencies are drawn out from each group's context, experience, and career stages which are highly different to produce a unified POE taxonomy that can be considered as one reference in using POE strategy.

POE Taxonomy based on Students and Teachers

The taxonomy of POE for students and teachers is shown in Figure 4. This shows their common competencies pertaining to typology, process, and structure of prediction, observation, and explanation strategy. The taxonomy implies that experiment can be more meaningful when it is socially constructed. In the classroom, the taxonomy reveals that the students and the teachers actively negotiate in the area of work with constant support and instruction. The socialization of ideas comes from student-to-student, student-to-teacher, teacher-to-student, student-to-more-knowledgeable-peer. Through these complex interactions, meaningful learning outcomes in doing experiments and in forming knowledge will happen.

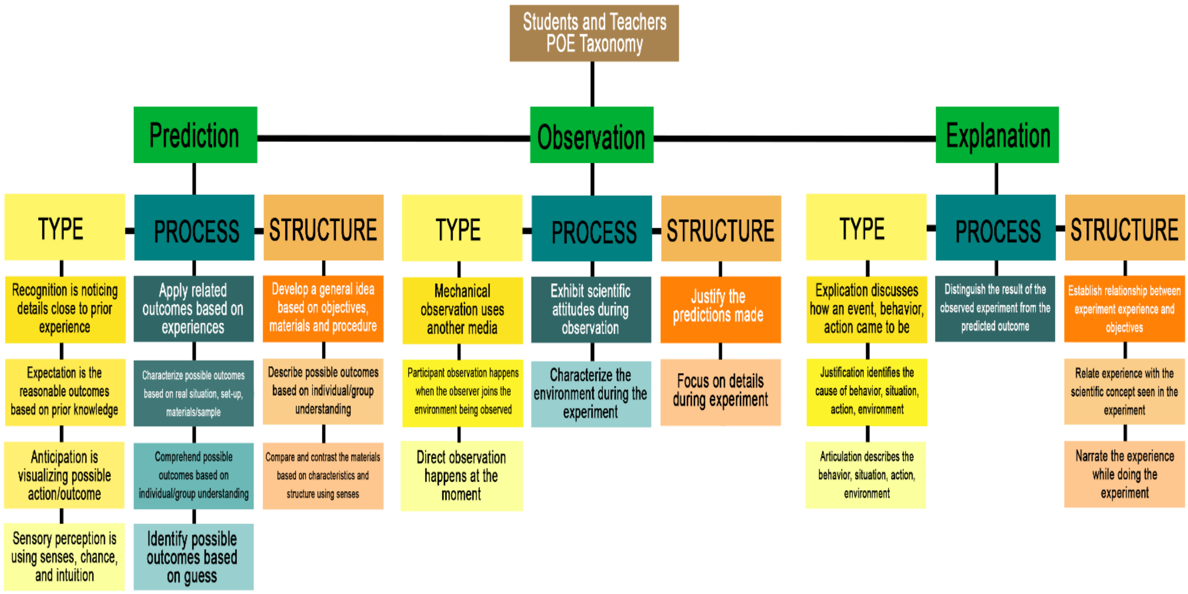

Figure 4. Hierarchical POE Taxonomy based on Common Students and Teachers' POE

Teachers and students have the most common processes and structures in the prediction and observation category, but only one common process under the explanation category distinguishes the result of the observed experiment from the predicted outcome. This means that in performing laboratory experiments in the classroom, the teachers and students may have commonalities in the manner of prediction and observation due to the same context, but since teachers are more experts than the students in using explanation strategy due to their career level, this explains why only one process of prediction strategy is similar with teachers and students.

Students and teachers have common taxonomies because the teachers provide an environment for students to experiment, experience, and simulate any scientific investigation. This is expressed in the research framework of this study that teachers and students are involved in the area of work and activity negotiated during the execution of the POE tasks. The constructivist model of chemistry stakeholders in the process of POE was observed during the classroom observation when the teacher and students performed the experiments in General Chemistry 2 using the POE strategy. The engagement of POE is predetermined which is why exposure to a variety of typologies, processes, and structures is important.

POE Taxonomy based on Teachers and Chemists

The POE taxonomy of teachers and chemists in Figure 5 shows the professional way of performing the experiment by using the predict-observe-explain strategy because when they predict the possible outcomes of the experiment, they relate possible outcomes based on prior knowledge through readings and research, and apply related outcomes based on experiences. The implication of taxonomy between teachers and chemists is to help them organize the appreciation of journals as the starting point of experimentation in the classroom and in the laboratory, and to extend the concept of these journals by proper facilitation of the experiment. The taxonomy is a guide on how a process can be structured.

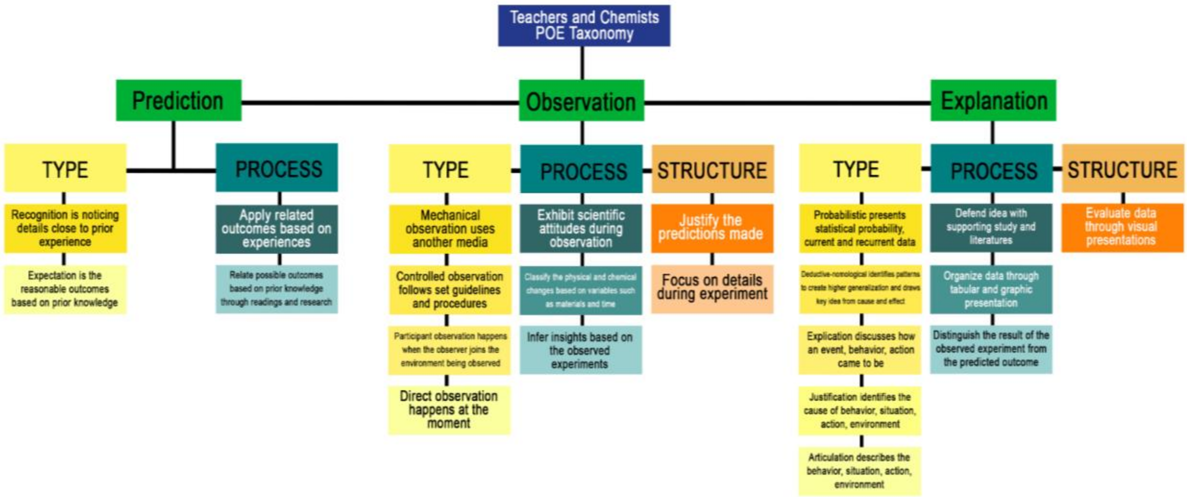

Figure 5. Hierarchical POE Taxonomy based on Common Teachers and Chemists' POE

The POE taxonomy of teachers and chemists also shows that in terms of prediction strategy, chemists and teachers have no similar structure because the chemists' way of performing the experiment does not rely on predicting outcomes since they have definite routines and procedures to follow. The other noticeable area in the POE taxonomy for teachers and chemists is the structure of explanation which is to evaluate data through visual presentations. This shows that they have different patterns in explaining the result of the experiment except in evaluating the data through visual presentations such as tabular or graphical presentations. Thus, low-level POE skills are assumptively embedded and are automatically a part of the experimentation due to their academic backgrounds and professional experiences.

POE Taxonomy based on Chemistry Stakeholders

The POE taxonomy of chemistry stakeholders in Figure 6 shows the common typology, process, and structure of how chemistry stakeholders exemplified POE strategy in performing the experiment. The result of the analysis of interview data implied the following concepts about the POE strategy: Prediction is becoming a biased or prejudice concept because the observation focuses on the correctness of his/her prediction; observation aims to develop manipulation and measurement skills in order to develop scientific attitudes, and explanation promotes the possibility of filtering data based on one's prejudice or bias. The primary concern of POE is to prove or disprove the predicted outcomes. Explanation is a reflection because one is becoming aware of how things work and make sense.

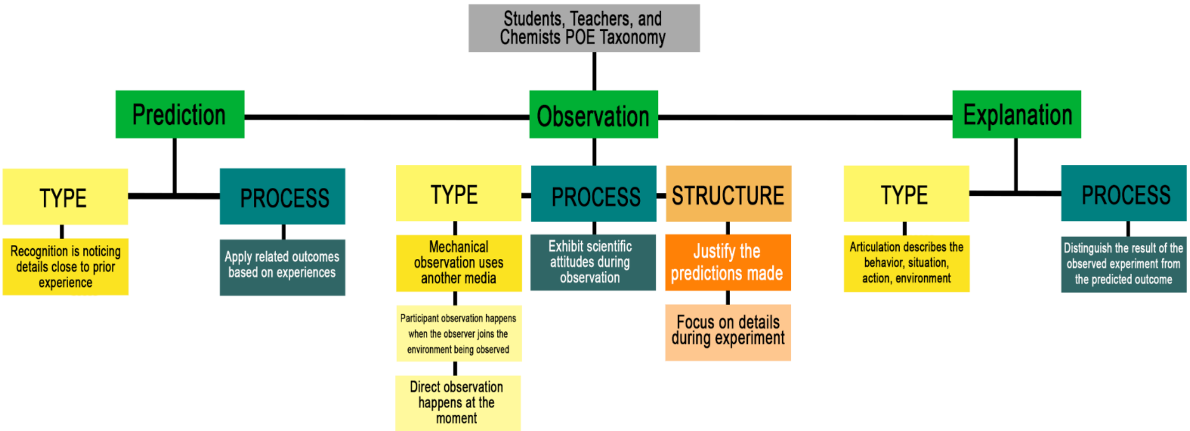

Figure 6. Hierarchical POE Taxonomy based on Common Students, Teachers, and Chemists' POE

The taxonomy for the POE strategy and the taxonomy for the stakeholders were presented in this study, revealing common patterns in how stakeholders implement the POE approach. The taxonomy showed the arrangement of the types, processes, and structures of prediction, observation, and explanation from the lowest level to the highest level of difficulty as thinking skills. Most of the POE strategies or skills that student-respondents applied are in the low-level types of POE, while the teachers' strategies or skills are at average level types of POE, and the chemists showed high-level types of POE. These observations became the reference on the leveling of the POE competency standards.

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