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# The Impact of Inquiry-Based ChemistryExperimentation on Eleventh-Grade Students' Science Inquiry Process Skills

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As the advocacy for active learning in science classrooms grows, so is the need to cultivate learners' competencies in scientific inquiry. In this parallel convergence mixed-methods study, we examined the science process skills of 221 eleventh-grade students in four out of 30 senior secondary schools, which were selected using a two-stage sampling technique. A six–week chemistry experimentation teaching using the 4-H Inquiry- in -Action model followed a pre-test. During experiments, qualitative classroom observations were made to describe students' science inquiry process skills. While the quantitative data were collected using the Science Inquiry Process Skills Inventory, the qualitative data were collected using the Event Sampling Observation Schedule. Grand findings show a meaningful level of acquisition of all of the science inquiry process skills under investigation. The skill to use evidence to answer scientific questions was relatively easy, and although students were more inclined to drawing and interpretation of graphs, they experienced initial challenges in designing their own experiments, making accurate measurements, and recording the masses and volumes of experimental samples. These results have underscored the need to employ guided inquiry learning strategies in the Liberian science classroom and hence serve to inform science curriculum reform programs in Liberia .

***Keywords**:* 4-H Inquiry - in - Action, measurement, recording, science education, science inquiry process skills

Science inquiry process skills are skills that are used by scientists to construct knowledge for solving scientific problems. Settlage and Southerland (2007) describe these skills as comprising inevitable procedures that constitute physical and mental approaches to solving scientific problems. Science inquiry process skills include problem identification, asking questions, experimenting, measuring, observing, classifying, data gathering, transforming, interpreting, and communication the data (Ġnce et al., 2010). Having been described as the focus of doing science, many scholars have underscored the greater importance of science process skills over the science content for more impactful learning (Çalık & Coll, 2012), and there is a

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widely held belief among teaching practitioners that the development of science inquiry process skills is a core objective of science education (Colvill & Pattie, 2002).

The last two decades have witnessed a growing interest in learners' science inquiry process skills on the grounds that it represents the attributes of scientists (Aktamis & Ergin, 2008; Feyzioglu et. al., 2012; Özgelen, 2012). Many studies, which tested the effects of inquiry-based approach to teaching on high school chemistry students have found greater achievement measures for the students' science process skills in Indonesia (Af'idayani et al, 2018), and Turkey (Balım, 2009; Koksal & Berberoglu, 2014; Şahintepe et al., 2020). With two versions of the inquiry-based model of teaching, in which the experimental group used models, the results showed no substantial overall difference between the independent groups, but phenomenal gains in the science process skills were observed within each group between pre-test and post-test mean scores. While the control group showed meaningful improvement in identifying variables and stating hypotheses, the experimental group experienced gains in identifying variables and stating hypothesis, operational definitions, as well as graphing (Ogan-Bekiroğlu & Arslan, 2014).

Buntern et al (2014) observed a significant positive difference in students' science concept achievement and the science process skills between an experimental group, which was taught using inquiry, and the control group, which was taught using demonstration. Also, Kuhn and Pease (2008) have reported meaningful gains made in the identification of scientific questions, interpretation of data and over time, supporting claims through inquiry-based teaching strategies. Also, the size of the effect of teaching on science inquiry process skills has been reported by Koksal and Berberoglu (2014) to be higher for inquiry-based instruction, than the demonstration method. Students' experiences in science experiments that have been documented include the inclination towards designing their own experiments (Galloway & Bretz, 2016; Koretsky et al., 2011; Yildirim, 2016), the dislike for graphing experimental numerical observation (Berber, 2013), malfunctioning and equipment (Deacon & Hajek, 2011).

These aforementioned scientific shreds of evidence demonstrate the power and potential of self-regulated learning engagements (Khan et al., 2020), and the inquiry-based teaching strategies for enhancing science inquiry process skills, which Aydogdu, (2015) considers most important for the retention and transfer of acquired scientific knowledge. According to Khalid et al., (2016), information overload threatens this retention and subsequent transfer of learning. Little wonder, a cross-section of the scientific community refers to science inquiry process skills as the most important element of scientific reasoning (Aydogdu, 2015), thus its inclusion in curricula at every level of science education is critical, as countries across the economic divide strive to strengthen their science education programs. Achieving this broad goal however requires a professionally trained and motivated science teacher population, material resources, and the administrative commitment to the overall goal of improving science education.

The abstract nature of chemistry and other sciences requires teaching strategies that sustain learners' attention and understanding. According to Said et al., (2016), experimentation like other hands-on activities has the potential to motivate learning. Although the Ministry of Education in Liberia in the right move, adopted a competency-based curriculum in 2018, that emphasizes practical activities in science classes, the inadequacy of science laboratory facilities, or the lack thereof has thwarted the Ministry of Education's initiative to enhance the quality of science education. However, even those schools, which marginally meet these needs are challenged with large class sizes. Therefore, experimentations are done almost exclusively by demonstrations, where the teacher directs the activities and manipulates the physical and cognitive processes of knowledge construction. Learning science in this fashion ultimately leaves the Liberian students with rote memorization of the concepts and procedures in scientific investigations, which may not adequately develop scientific attributes.

It is not very surprising, therefore, that in recent years, the Liberian candidates' performances in the West African Senior Secondary Certificate Examinations (WASSCE) have been described by the West African Examinations Council's (WAEC) Chief Examiners' report as below average (WAEC, 2016) or very poor (WAEC, 2017). This persistent suboptimal performance in chemistry may not be unconnected with the prevailing teaching strategies. On the basis of the aforementioned, we sought to examine the science inquiry process skills of grade eleven students of Bong County in Liberia, in the hope that the outcome will serve as a baseline, upon which further studies will be conducted. The overarching justification for the selection of the eleventh grade class in this study was the teachers' overwhelming expressed consent for cooperation.

**Research aim and question**

This study aimed to examine the effects of the 4-H Inquiry – in - Action on grade eleven students' science inquiry process skills. To achieve this aim, the following research questions further guided the study.

1. How do students' science inquiry process skills compare before and after the implementation of the inquiry-based experimentation teaching?
2. What are students' experiences in the 4-H inquiry-in-action chemistry experimentations that were meant to enhance their science inquiry process skills?
3.

## Method

In this mixed-methods study, the Convergence Parallel Mixed-methods design was used. This design involved the collection and analysis of the quantitative and qualitative data at about the same time. Thereafter, mixing and integration of the findings of the two kinds of data enriched the grand findings and led to better interpretation of said findings (Creswell, 2014). This design allowed for the comparison of the quantitative and qualitative findings, and to find possible explanations for contradictions and divergence between the two types of findings. The quantitative component of the study used the One Group Pre-test / post-test Design illustrated in Table 1.

**Table 1**

*The one- group pre-test /post-test design*

| O | X | O |
|---|---|---|
| Pre-test | treatment | Post-test |

*Source: Adapted from Frankael et al., (2012).*

In order to ascertain participants' initial perceived science inquiry process skills, a pre-test was administered to the students. Thereafter, instructional intervention, which lasted six weeks followed. Post-tests were administered after the closure of instructions in the following week. Classroom experiments were qualitatively observed in the course of the instructional intervention. At the end of every observation, the field notes were immediately collated and harmonized. This way, information missed by one observer was captured by the other, thus contributing to the overall trustworthiness of the process of data collection.

**Study participants**

Four schools were purposively selected from a total of 30 on the basis of the availability of laboratory facilities and conducive space for experiments. 221 (135 male and 86 female) students whose mean age was 17 years comprised the sample of study participants. This sample was drawn from a population of 754 students. These figures represent the experimental group of a previous study (Langenhoven & Stevenson-Milln, 2022) for which the current study is a follow-up.

**Instruments and procedures**

The Science Inquiry Process Skills Inventory (SIPSI) in Appendix B, adopted from Arnold et al., (2013) was used to gauge students' level of acquisition of science inquiry process skills. The SIPSI was crafted in line with the 4-H Inquiry - in - action model of science instruction (Appendix A) by the same authors. The SIPSI comprises 11 items each of which measures an important process skill. The Event Sampling Observation Schedule (ESOS) was researcher designed for recording the verbal and non-verbal observations at every stage of the 4-H Inquiry- in-action process. The outcomes of the ESOS were integrated into the field notes for a thorough description of students' science inquiry process skills in the experiments.

The SIPSI was pilot tested with 41 students from one of Bong County's senior high schools after validation. The Cronbach Alpha reliability was computed in SPSS Version 26.0 and found to be 0.80., indicating internally consistent items (Fraenkel et al., 2012). Every classroom observation and hence recording of events was done by two members of the research team, and the independent records were collated immediately for reliability.

**The 4-H inquiry – in - action lesson**

*Solutions* was selected from the Eleventh - grade Liberian National Curriculum on the basis that it is listed among the topics identified as either the least attempted or the least scored in the WASSCE (WAEC, 2016, 2017). The typical class started with the teacher motivating the students by asking a few questions aimed at identifying misconceptions. Thereafter, and in groups of four or five, students were provided with the topic for investigation, as well as the apparatus and reagents needed for the experiment, and asked to carry out a cycle of scientific inquiry by (i) asking a scientific question that will be answered using evidence,(ii) designing an experiment in diagrams,(iii) conducting the experiment according to the design, but the design must be approved by the teacher,(iv) correctly recording observations, (v) presenting the results in tables, (vi) where necessary, plotting the results on graph sheets (vii) explaining the findings to the cooperative and larger (entire class) groups,(viii) and answer the research question that was asked at the beginning of the inquiry using scientific evidence. The experimental activities are found in Appendix C. The teachers' role was to circulate among the cooperative groups to offer appropriate and timely guidance.

As much as possible, teachers refrained from providing explicit responses to questions but rather asked a leading questions in place of an answer. Teachers exercised wait time to allow students to process the information before verbalizing it. These strategies cultivated critical thinking, which is one of the core competencies that inquiry instruction is meant to achieve.

Figure 2. Students working in cooperative groups

Figure 3. Students exploring the density as a distinguishing property of liquids

Figure 4: Students exploring the difference between true solution and suspension using filtration

Figure 5. Students using a triple beam balance to determine the mass of a solid (sodium chloride)

**Data analysis**

The SIPSI data were placed on an Excel spreadsheet for computation of the composite totals and mean scores. The mean change in the acquisition of the process skills was calculated using the formula.

$$\%\, mean\ difference\ = \frac{posttest\ score - pretest\ score}{pretestscore} \times 100$$

Thereafter, the composite totals were fed into SPSS Version 26.0 for analysis of the shape of the data. Based on the skewed distribution of the scores, which implied that the normal distribution condition was violated even by indication of a Shapiro-wilks value of .017, and box plot shown in Table 2 and figure 6 respectively, a non-parametric statistic, the Wilcoxon Signed Rank Test was used to compare the means of pre-test and post-test science inquiry process skills scores at $\alpha = .05$ level of significance.

**Table 2**

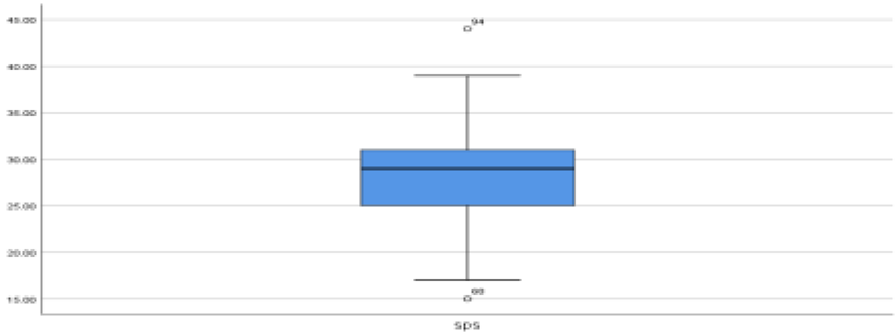
*Results of test for normality of science inquiry process skills scores*

**Tests of Normality**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| sps | .111 | 169 | .000 | .980 | 169 | .017 |

a. Lilliefors Significance Correction

**Figure 6. A box plot of scores of the science inquiry process skills**




Theoretical thematic analysis patterned after Braun and Clarke (2006), was conducted by the researcher and three research assistants; all of whom are knowledgeable in qualitative data analysis. The theoretical (deductive) thematic analysis was preferred because of the need to align participants' focused responses with the specific research questions. Therefore, coding was more specifically aligned with the research questions.

## Results

The section that follows displays the result of the analysis of the quantitative data, followed by the qualitative data.

**Table 2**

*Results of mean scores per item of students' science inquiry process skills*

| Science inquiry process skill | Pre-test mean score | Post-test mean score | Mean difference | % mean difference |
|---|---|---|---|---|
| Using scientific knowledge to form a question | 2.51 | 2.70 | 0.19 | 7.56 |
| Asking a question that can be answered by collecting scientific data | 2.32 | 2.57 | 0.25 | 10.78 |
| Designing a scientific procedure that leads to answering a question | 2.31 | 2.60 | 0.29 | 12.55 |
| Communicating a scientific procedure to others | 2.21 | 2.51 | 0.30 | 13.57 |
| Recording scientific data correctly | 2.47 | 2.57 | 0.10 | 4.05 |
| Drawing a graph of scientific data for presentation to others | 2.12 | 2.59 | 0.47 | 22.17 |
| Displaying data and observations for better communication | 2.24 | 2.47 | 0.23 | 10.27 |
| Analyzing the results of a scientific investigation | 2.41 | 2.57 | 0.16 | 6.64 |
| Using appropriate science terms to share and explain results | 2.39 | 2.58 | 0.19 | 7.95 |
| Using models to make explanations of results better | 2.13 | 2.45 | 0.32 | 15.02 |
| Using the results in the investigation to answer the question that I initially asked | 2.65 | 2.77 | 0.12 | 4.53 |

An examination of Table 2 shows that three skills related to data presentation and communication; the skill to communicate a scientific procedure to others, the skill to use scientific terms to share results and the skill to use models to explain results, show mean differences of 13.57%, 7.95% ,and 15.02% respectively. Therefore, with respect to data presentation and communication, the greatest and least perceived gains were made in the skill to communicate a scientific procedure to others, and the skill to use scientific terms to share results respectively. Data recording is the least improved skill with a mean difference of 6.64%. The skill to design experimental procedure shows one of the highest mean difference, 12.55%, second only to the skill to draw graphs (22.17%). The students showed the acquisition of the skill to use evidence to answer a scientific question by a mean difference of 4.53%. This represents the second least developed skill.

**Table 3**

*Results of Wilcoxon Signed Rank Test for SIPSI pre-test and post-test scores*

| | | **Wilcoxon Signed Rank Test** | | | **Test Statistic** |
|---|---|---|---|---|---|
| | | N | Sum of Ranks | Mean Ranks | *p* |
| **Post-test-pre-test** | **Negative Ranks** | 65 | 4599.50 | 70.76 | 0.001 |
| | **Positive Ranks** | 96 | 8441.50 | 87.93 | |
| | **Ties** | 8 | | | |
| | **Total** | 169 | | | |

*p < 0.05, difference is significant

The result in Table 3 shows a higher positive mean rank than negative mean rank, implying that the post-test mean score is, on average higher (87.93) than the pre-test mean score (70.76). The associated p-value for this test is < 0.05, indicating that the difference in the mean ranks is found to be statistically significant. Following are the results of qualitative observation of science inquiry process skills.

**Table 4**

*Themes in the classroom observation on science inquiry process skills*

| **S/N** | **Related Inquiry science process skills** | **Themes generated** |
|---|---|---|
| **1** | questioning as a science inquiry process skill | Students slowly developed the skill to construct inquiry questions |
| **2** | Data display, presentation and communication | Students were excited about drawing solubility graphs and experimental designs |
| **3** | Designing scientific procedure for exploitation | Designing experiment is the most difficult skill in scientific inquiry |
| **4** | Data recording and analysis of scientific inquiry | Measurement and recording masses challenged students |
| **5** | Using evidence to answer a scientific question | Answering the inquiry question was relatively easy |

Following is an elaboration on the five themes in Table 4

**Theme 1: Students slowly developed the skill to construct inquiry questions**

Students could either ask dichotomous questions or generic questions at the beginning of the intervention. Students' questions predominantly started with "what". Fine-tuning and appropriately narrowing the questions down to a specific inquiry item initially posed a challenge but this was overcome once the students realized after several failed attempts that starting a question with "*is*" will overly narrow the scope of response to a *yes"* or *no*. Students gradually learned from the class experience that a good scientific inquiry question that seeks sufficient exploration starts with "*how*" and *"what"*. Therefore, towards the middle of the intervention, students demonstrated fairly good knowledge of scientific questioning skills. The two items that pertained to the level of questioning skills; one being the skill to use scientific knowledge to form a scientific question, and the other, the skill to ask a scientific question that can be answered by collecting data, could not be distinguished, since forming a question is a cognitive process, and cannot be directly observed, but can only be determined from the resulting question that is asked, after the cognitive processes of forming the question.

**Theme 2: Students are excited about drawing solubility graphs**

Students demonstrated excitement about drawing of solubility graphs in classroom observations, much more than they did in drawing diagrams on poster sheets for display. This preference was demonstrated in the observed clamoring to draw the axes, locate the point, and join the points on the graph. Therefore, literally, every segment of the graphing activity aroused students' interests. However, the most demonstrated ability was in the use of scientific terms, followed by the communication of scientific procedures to others. The most difficult skill observed was the use of models to explain results. However, the most highly demonstrated ability was the use of scientific terms, followed by the communication of scientific procedures to others. The most difficult skill, revealed in classroom observations, was the use of models to explain results.

**Theme 3: Designing experiment is the most difficult skill in scientific inquiry**

Students encountered lots of difficulties in figuring out the experimental procedures although the materials needed for the experiments were provided. Teachers initially provided a tactful guide, until students gradually realized that the procedure really depended on the materials present. It worked more or less like a jig-saw puzzle. Realizing this, students started to suggest procedures. Although time – consuming, this gave rise to a gradual mastery of the skill with time. With this mastery came a heightened interest and motivation to design their own experiments. Therefore, a meaningful gain in this skill was realized towards the end of the intervention.

**Theme 4: Measurement and recording challenge students**

Principally, the measurement of masses using the triple beam balance posed a challenge to students. Most students made frequent errors in subtracting the mass of the beaker from the total mass of the beaker and salt, to obtain the mass of the salt. Also, correctly reading volumes on graduated cylinders, and thermometers temperatures was initially difficult. Students recorded data with difficulty, especially given that they were challenged in the use of consistent decimal places in reporting.

**Theme 5: Answering the inquiry question is easy**

Students demonstrated satifactory skills in using evidence to answer a scientific question. Classroom observation notes indicate students' emphatic use of data as evidence in their responses to scientific questions. Once the experiment was conducted, and the findings were clearly written, students realized even at the start of the interventions that answering the inquiry question required just using the findings as evidence in answering said science inquiry question.

## Discussion

**Integration of quantitative and qualitative findings**

Quantitative results show that every skill under investigation was enhanced to varying extents. The first three highly acquired skills in decreasing order being; the skill to create a graph for presentation to others, the skill to use models to explain results, and the skill to communicate a scientific procedure to others. The least three acquired skills in decreasing order are; the skill to analyze the results of a scientific investigation, the skill to use the results of investigation to answer the scientific question, and least, the skill to record data accurately.

The qualitative data supports the quantitative findings to a large extent in the sense that students developed the skill to construct inquiry questions slowly. Also, the fact that students' excitement was drawn from the graphing activity and gradually mastered the skills for designing experiments is also an indication of gain. The most enhanced skill being the skill to create a graph for presentation to others was confirmed by the qualitative finding. Those skills that posed serious challenges to students were gradually overcome with time. Therefore, it can be implied that the two types of results support each other and converge on a grand finding that students' science inquiry process skills were significantly enhanced by the inquiry-in action model of teaching chemistry experiments.

The divergence in the outcomes of the two types of data regarding the most and least gained skills suggests the presence of an unknown variable. Most probably, this observation may just have come from the limited representativeness inherent in qualitative samples compared to quantitative ones. However, irrespective of this unexpected observation, both types of data converge at the finding that the 4-H Inquiry- in- action model of teaching improves all 11 science process skills under investigation. This grand finding is conclusive and consistent with those of Af'idayani et al., (2018) in Indonesia and (Balım, 2009), Koksal and Berberoglu (2014) and Şahintepe et al., (2020) in Turkey.

The finding that drawing of solubility graphs tended to attract students' attention more than diagrams on poster sheets and sheets of paper may have been derived from the newness of the activity on one hand, and the interest generated from the systematic nature of graph plotting on the other. Given that this activity represents the highest score in the quantitative data, and the fact that it is supported by the qualitative findings, it may be worthwhile to suggest that graphing is a motivating activity in science teaching, and it should be encouraged in science classes. Ogan-Bekiroğlu and Arslan, (2014) also realized great improvement in students scientific skills that included graphing. However, drawing graphs does not always excite students as revealed in the study of Berber (2013). Students in this study feared graphical representation of data in addition to unit conversion. These contradictory findings probably imply that the type of activity that excite learners is context dependent.

Students' skill to form and ask scientific questions developed with time and practice. Most students initially found it difficult to ask specific questions related to the investigations. A typical question presented in one group on an activity to determine the effect of temperature on the rate of dissolution of a salt was

*What will be the reaction between the salt and water at different temperatures?*

After several prompts and guidance, the students figured out that the question was derived from the title of the activity. After several trials, and when eventually the teacher led them to writing the inquiry question. One student discovered the trick in writing the inquiry question from the title of the inquiry in the following statement:

*I know now how to write the question; just replace the "to determine" at the beginning of the title of the activity with "What is" and put a question mark at the end.*

Therefore, if the activity is; *to determine the effect of temperature on the rate of dissolution of a salt, the investigative or scientific question would be; what is the effect of temperature on the rate of dissolution of the salt.*

Although the quantitative finding suggests that student found it harder to form questions than asking questions, observation field notes could not delineate these two skills, because the mental process of forming a question is latent, and could not be observed directly. To find students being more challenged with forming scientific questions than asking a scientific question, after being formed is expected, because as Reiff (2002) puts it, the hardest thing to do is to ask the right question, which depends on how the questions are formed. The students' demonstration of questioning skills seems a key indicator of the overall success of the 4-H inquiry model of instruction. Wide divergence in the two types of findings on data communication skills, may be indicative of a truly multi-level skilled class.

Designing experiments constituted an early challenge, which may have been caused by its strangeness in an education system where instructions are neither patterned after scientific inquiry investigations, nor do WAEC tests reflect guided inquiry items. It is not entirely surprising that the quantitative finding shows considerable improvement in this skill, because classroom observation shows an initial difficulty, which was eased towards the end of the intervention. This activity apparently posed a similar challenge in the studies of Galloway and Bretz (2016), Koretrsky et al (2011) and Yidirim (2016). However, one thing that is common to all, is that irrespective of this challenge, the students acquired and developed the skills to design their own experiments with time.

Classroom observation revealed that the low mean scores on the skill to record scientific data may have come from the difficulties encountered by students in calibrating, weighing and recording masses. This is similar to the observation in Deacon and Hajek's (2011) study, where students complained about defective and malfunctioning equipment. The students in this study encountered difficulties with triple beam balances in determining the masses of solids and yet demonstrated motivation to design their own experiments. Students were frustrated with these measurements, and had to spend several minutes getting a dependable reading that will be acceptable by all group members. Students were not accustomed to ensuring consistency in units of measurements and decimal places for scientific measurements and reporting.

**Conclusion and implications**

This study aimed to examine the science inquiry process skills of grade eleven students in Bong County. Although there is an initial difficulty with getting students to acquire mastery in skills that they are not too often exposed to, this can be overcome with appropriate guidance in teaching. The study has found that the 4-H Inquiry – in - action model of teaching is effective in enhancing all 11 science inquiry process skills under review to varying extents. Students find the skill to use scientific evidence in data to answer scientific question reactively easy. Students are most excited about drawing and interpreting graphs of solubility. However, they appear to be more challenged by the acquisition of the skills to design experiments, make accurate and precise measurements of masses and volumes of experimental samples.

These results have underscored the need to employ guided inquiry learning strategies in the Liberian science classroom and should serve to inform curriculum reform programs in Liberian science education. This further implies that teachers' professional developments in science inquiry process skills is critical to the students' long term acquisition of these skills. Specifically, teachers' investment of time and energy in developing students' skills to design experiments and make accurate measurements in laboratory activities is needed. Emphasis should be made on students' inquiry process skills in science activities because these truly represent and identify scientists.

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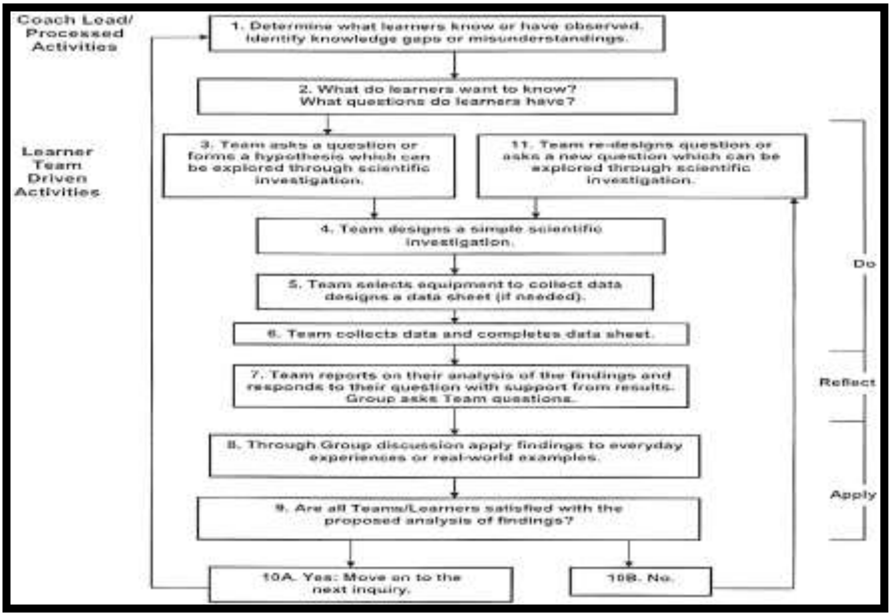
## Appendix A: The 4-H Inquiry-in Action Model




## Appendix B: Science Inquiry Process Skills Inventory

**Section A: Background information of respondent**

1. Age: ----------
2. Sex/gender (Place a tick in one of the boxes as applicable to you).

a. Male: ☐

b. Female: ☐

3. Name of school: ____________________________________________

**Section B: science process skills scale**

Below is a scale that has statements/sentences called items in the middle. Carefully read each statement and then circle (○) one of the options (**N, ST, U, A**) on the right of the scale that most appropriately applies to you under the response column. In the response column,

N = Never
ST = Sometimes
U = Usually
A = Always

| Item | Item | Responses | | | |
|---|---|---|---|---|---|
| **1** | I can use scientific knowledge to form a question | **N** | **ST** | **U** | **A** |
| **2** | I can ask a question that can be answered by collecting data | | | | |
| **3** | I can design a scientific procedure to answer a question | | | | |
| **4** | I can communicate a scientific procedure to others | | | | |
| **5** | I can record data accurately | | | | |
| **6** | I can use data to create a graph for presentation to others | | | | |
| **7** | I can create a display to communicate my data and observations | | | | |
| **8** | I can analyze the results of a scientific investigation | | | | |
| **9** | I can use science terms to share my results | | | | |
| **10** | I can use models to explain my results | | | | |
| **11** | I can use the results of my investigation to answer the question that I asked | | | | |

**Instructions for handing in the survey sheet**

Thank you for completing this survey sheet. Please carefully go over the responses to be sure that you have selected the right responses. Thereafter, please make sure to hand in the survey sheet to the research assistants. Once more, I thank you for your time and kind cooperation.

## Appendix C: Experimental Activities

**Activity 1: The effect of particle size of a solid on its solubility in a liquid**

Students were provided with the following
4 cubes of sugar
6 test tubes
1 Wash bottles containing water
1 stopwatch

In this activity, students in their groups were given the following instruction.

In your respective group and using the materials provided,

1. Design an experimental procedure to determine the effect of the molecular size of sugar (solute) on its solubility in water (solvent).
2. Carry out the investigation, make keen observations and record your observations on a sheet. Data should include
a. time taken for the sugar samples to dissolve,
b. temperatures of the water
3. Note your observation
4. What is the practical everyday application of this investigation?

**Activity 2: The effect of temperature on the solubility of a solid in a liquid**

Students were provided with the following
4 Sugar cubes
1 Thermometer
3 beakers holding water at 3 different temperatures
6 Test tubes

In your respective group and using the materials provided,

1. Design an experimental procedure to determine the effect of temperature on the solubility of sugar (solute) in water (solvent).
2. Carry out the investigation, make keen observations and record your observations on a sheet. Data should include
a. the temperature of the water in the beakers just before pouring it.
a. time taken for the sugar samples to dissolve,
c. date and time, and
d. names of group members.
3. Note your observation

4. What is the practical everyday application of this investigation?

**Activity 3: The effects of intermolecular forces on miscibility and solubility of one liquid in another**

The materials provided were as follows;
6 test tubes
5 beakers, one each containing water, kerosene and vegetable oil, vinegar, green alcohol
3 test tube holders
In your respective group and using the one set of materials at a time,

1. Design an experimental procedure to determine the effect of intermolecular forces on the solubility of two liquids.
2. Carry out the investigation, make keen observations and record your observations on the activity sheet. Data should include responses to the following
a. which two liquids are miscible?
b. why are the two liquids miscible?
c. which liquids are immiscible
3. Note your observation
4. What is the practical everyday application of this investigation?

**Activity 4: Plotting and interpreting solubility graphs**

The table below shows experimental values of solubility of $KNO_3$ per 100mL of water measured at different temperatures.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Solubility(g/100mL | 35.1 | 50.0 | 60.2 | 90.0 | 110.0 | 140.0 | 140.0 | 140 |
| Temperature($^0$C) | 25 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |

A. Plot the graph of the solubility of $KNO_3$ [The plotted graph is attached]
B. Indicate on the graph area that shows
   (i)unsaturation,
   (ii) saturation and
   (iii) supersaturation
A. From the graph, indicate the solubility of $KNO_3$ at $55^0$C
B. At what temperature will 80g of $KNO_3$ solution be exactly saturated in $100cm^3$
C. What mass of salt will precipitate if it is cooled from $85^0$C TO $55^0$C?
D. If 20g of $KNO_3$ has been added to $100cm^3$ of water at $30^0$C, how much solute must be added in order to make it saturated?