Student-Designed Inquiry: Effects on Scientific Reasoning and Conceptual Understanding in Physics

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The study investigated the effects of Student-Designed Inquiry (SDI) on students' scientific reasoning and conceptual understanding in Physics. The study showed that exposure to SDI could help in developing students with high reasoning ability. SDI favored high-performing students than low-performing students in enhancing conceptual understanding. Also, scientific reasoning positively predicted conceptual understanding in physics. Moreover, students with high reasoning ability had higher conceptual understanding. Students with average reasoning ability also performed significantly better in the Conceptual Understanding Test than students with low reasoning ability.

Further investigation can be carried out, for example, on the effects of SDI to other learning outcomes such as science process skills, higher-order thinking skills, self-efficacy and attitude.

Introduction

Science education in many countries envisions a scientifically literate citizenry, as scientific and technological issues begin to dominate national discourse i.e., climate change, environmental concerns, revolutionary technologies, and new scientific discoveries. Scientific literate individuals help shape a nation by forming informed opinions and choices. To address the problem of producing scientifically literate citizens, the United States commissioned the National Research Council to write the National Science Education Standards that emphasize learning of concepts and principles through inquiry (Minner, Levy, and Century, 2009). In the Philippines, the K-12 Basic Education Program that is currently undertaken by the Department of Education echoes educational goals that are geared towards molding literate and thinking individuals by calling attention to inquiry-based, constructivist, and integrative pedagogical approaches (DepEd, 2010). Inquiry-based science instruction or training has been reported to positively impact students' conceptual understanding (Minner, Levy, and Century, 2009), student participation, and classroom grade (Tretter and Jones, 2003). Furthermore, Salter and Atkins (2011) have demonstrated how student-generated scientific inquiry provides students more developed understanding of the nature of science and enhances students' attitude toward science and open-inquiry.

Scientific literacy is also deemed vital in facilitating national development. Many nations strive to sustain their lead in science and technology. An integral part of scientific literacy is scientific reasoning. Lawson (2007) underscored its role by saying that the very heart of scientific literacy is effective reasoning. Graduates nowadays are expected to have excellent critical thinking and scientific abilities, such as reasoning, in order to thrive in a competitive and fast changing world (Bao et al., 2009).

The 2009 National Achievement Test score of 43.40 showed Filipino students' average mastery in Science ("National Achievement Test: An Overview, presentation of Dr. Benito, May 2010). A possible reason for the inability of some students to grasp the concepts taught in high school is the students' lack of scientific reasoning ability (Coletta and Phillips, 2005). This also hinders their learning in high school as well as their success in college. The same study established how higher scientific reasoning can result in greater gains in a university physics class despite a weak high school physics background. Lawson (2007) added that reasoning deficiencies impede students' problem solving skills, conceptual understanding, and ability to reject misconceptions.

A study done by Bao et al. (2009) involving introductory physics students showed that traditional training in content knowledge is not enough to improve students' general reasoning abilities and that instructional methods and strategies that will help students develop both content understanding and reasoning ability should be created. Schen (2007) reported that some of the studies in the development of scientific reasoning are descriptive about the reasoning skills of students from across grade levels. Though there are some existing studies that focus on the development of scientific reasoning skills such as in physical science and introductory physics course (Etkina, 2007). Coletta and Phillips (2005) mentioned that Karplus in 1979 devised instructional methods that aim to improve one of the components of scientific reasoning ability, proportional reasoning skills of high school students. No recent study so far has focused on the development of both scientific reasoning skills and conceptual understanding.

In line with the results and recommendations of the aforementioned studies, student-generated inquiry was conceptualized as a feasible instructional approach that could help students develop both content understanding and reasoning ability.

Scientific Inquiry

Scientific inquiry, as the overarching goal of scientific literacy, has been defined in diverse ways by researchers. According to Tang et al.(2009) and Barrow (2006), the lack of agreement on the meaning of inquiry in the field of science education makes it a contested term. For instance, Llwellyn (2002) defines it as seeking for truth, information, or knowledge through questioning. He views it as the key means for learners to extend their understanding of the natural and human-made environment that constitutes active learning, which combines mental and physical activity. On the other hand, Martin-Hansen (2002) describes inquiry as the kind of work that scientists do to make sense of the natural world by proposing explanations that are based on evidence. In the US National Science Education Standards (NSES), inquiry is interpreted as a multifaceted activity that involves

> "(1) making observations, (2) posing questions, (3) examining books and other sources of information to see what is already known (4) planning investigations, (5) reviewing what is already known in light of experimental evidence, (6) using tools to gather, analyse and interpret data (7) proposing answers, explanations, and predictions and (8) communicating the results. Inquiry also requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations" (NRC, 2000, p.23).

The US National Science Teachers Association (NSTA, 2004), on the other hand, gives a slightly different definition:

> "Scientific inquiry is a powerful way of understanding science content. Students learn how to ask questions and use evidence to answer them. In the process of learning the strategies of scientific inquiry, students learn to conduct an investigation and collect evidence from a variety of sources, develop an explanation from the data and communicate and defend their conclusions" (NSTA, 2004, p.1).

The NSES (NRC, 1996) present three perspectives of inquiry: (a) cognitive abilities that students must develop; (b) an understanding of methods used by scientists to search for answers for their research questions; and (c) a variety of teaching strategies that help students to learn about scientific inquiry, develop their abilities of inquiry and understand science concepts.

Inquiry as way of knowing focuses on the fundamental understandings about scientific inquiry so that students will develop meaning about science and how scientists work. The six categories specified by the NRC (1996) are as follows:

1. Conceptual principles and knowledge that guide scientific inquiries;
2. Investigations undertaken for a wide variety of reasons – to discover new aspects, explain new phenomena, test conclusions of previous investigations, or predictions of theories;
3. Use of technology to enhance the gathering and analysis of data to result in greater accuracy and precision of data;
4. Use of mathematics and its tools and models for improving the questions, gathering data, constructing explanations, and communicating results;
5. Scientific explanations that follow accepted criteria of logically consistent explanation, follow rules of evidence, are open to question and modification, and are based upon historical and current science knowledge, and
6. Different types of investigations and results involving public communication within science community

The fundamental abilities necessary to do scientific inquiry as identified by NRC (1996) are as follows:

1. Identify questions and concepts that guide scientific investigations;
2. Design and conduct scientific investigations;
3. Use technology and mathematics to improve investigations and communications;
4. Formulate and revise scientific explanations and models using logic and evidence;
5. Recognize and analyze alternative explanations and models; and
6. Communicate and defend a scientific argumentation

Science teachers are required to provide students with multiple opportunities in conducting investigations to accomplish these six abilities. The type of investigation referred herewith does not include verification laboratory experience. NRC (2000) goes on to say that practicing inquiry helps students develop their critical thinking abilities, scientific reasoning and deeper understanding of science.

In 2000, the NRC provided additional clarifications about inquiry being presented as content, process skills, or teaching strategies in the preceding policy document, NSES. The NRC identified five essential features of inquiry, regardless of grade level as follows: (1) scientifically oriented questions that will engage the students, (2) evidence collected by students that allows them to develop and evaluate their explanations to the scientifically oriented questions (3) formulates explanations from evidence, (4) connect explanations to scientific knowledge and (5) communicate and justify explanations. Table 1 shows how Singapore science builds on these essential features to guide inquiry-based teaching and learning (Ministry of Education, 2008).

Inquiry-based learning can be student-directed inquiry or teacher-directed inquiry, depending on the level of students' involvement in posing and responding to question, designing investigations, and evaluating and communicating their learning. Singapore science recommends experiences that vary between student-directed and teacher-directed inquiry (Ministry of Education, 2008).

To facilitate inquiry-based teaching and learning and to further emphasize the learning of science, teachers must incorporate these essential features of inquiry to teaching strategies.

Minner, Levy and Century (2009) have developed a framework for describing inquiry-based instruction which can be characterized as having three aspects: (1) the presence of science content, (2) student engagement with science content and (3) student responsibility for learning, student active thinking, or student motivation within at least one component of instruction – question, design, data, conclusion, or communication.

This study takes into account these variations created by differing views on inquiry learning and teaching as well as the fact that inquiry is a continuum. It also attempts to explore this continuum by introducing student-designed inquiry.

Scientific Reasoning

Scientific Reasoning (SR), "includes the thinking skills involved in inquiry, experimentation, evidence evaluation, inference and argumentation that are done in the service of conceptual change or scientific understanding" (Zimmerman, 2005, p.1). In a meta-analysis study done in 2007, Zimmerman identified 8 specific set of skills in scientific reasoning. These are (1) isolation and control of variables,(2) producing the full set of factorial combinations in multivariable tasks, (3) selecting an appropriate design or a conclusive test, (4) generating experimental designs or conclusive tests, (5) record keeping, (6) inductive skills implicated in generating a theory to account for a pattern of evidence, and general inference skills involved in reconciling existing beliefs with new evidence that either confirms or disconfirms those beliefs (Zimmerman, 2007).

Students' reasoning abilities in the science education area are commonly referred to as scientific reasoning and formal reasoning (Lawson, 1995). Scientific reasoning is a general scientific ability related to critical thinking and reasoning. It is also a methodology that is critical in enabling the successful management of real-world situations (Bao et al., 2009). Several studies recognize scientific reasoning as an important component of scientific literacy. Scientific reasoning and habits of mind sit at the heart of scientific literacy (Hand, Prain &Yore, 2001 in Piraksa, Phaprom, Artdej,& Srisawasdi, 2011).

Scientific reasoning skills can be developed through training and can be transferred. Training in scientific reasoning may also have a long-term impact on student academic achievement (Bao et

Table 1. Indicators of Student Self-direction and Teacher Guidance in Science Inquiry

Essential features of science as inquiry	More	Amount of Student Self-Direction		Less
	Less	Amount of Guidance from Teacher or Material		More
Question Students engage with an event, phenomenon, or problem when they …	Pose a question	Select among the question	Sharpen or clarify question provided	Accept given question
Evidence Students give priority to evidence when they…	Determine what constitutes evidence and collects it	Are directed to collect certain data	Are given data and asked to analyze	Are given data and told how to analyze
Explanation Students construct explanations when they…	Formulate their own explanation after summarizing evidence	Are guided in process of formulating explanation from evidence	Are given possible ways to use evidence to formulate explanation	Are provided with evidence
Connections Students evaluate their explanations when they…	Examine other resources and form links to explanations	Are directed toward sources of knowledge	Are given possible connections	Are provided with connections
Communication Students communicate and justify their explanations when they …	Form reasonable and logical argument to communicate explanations	Are coached in development of communication	Are provided guidelines for communication	Are given steps and procedures for communication

Note: Adapted from Inquiry and the National Science Education Standards, National Research Council, (2000, p.29).

al., 2009; Moore and O'Donnell, 2011).

Method

Sample

The study involved sixty (60) grade 10 students from two intact heterogeneous sections at a laboratory school in Diliman, Quezon City. The assignment of the two classes as SDI group and conventional group was determined randomly by tossing a coin.

The Instruments

1. Conceptual Understanding Test (CUT)

   The Conceptual Understanding Test (CUT) is a researcher-constructed, multiple choice type of test that assesses students' conceptual understanding in waves, light and geometric optics. The initial form of the CUT consisted of 60 multiple-choice type items. It was field-tested involving 60 students taking up introductory physics (Physics 80 series) at the University of the Philippines Los Banos. The final instrument was reduced to 35 items, with a Cronbach Alpha coefficient of .705.

2. Lawson's Classroom Test of Scientific Reasoning (LCTSR)

   The LCTSR was developed by Anton E. Lawson in 1978. The first version of the test consisted of 15 items. Each item involved a demonstration using some physical materials and apparatus that either pose a question or call for a prediction. The test assessed combinatorial reasoning, probabilistic reasoning and proportional reasoning. Items involving conservation of weight and displaced volume were also included because the two items were found to be good indicators of late concrete and early formal operational reasoning. The updated version of the test is composed of 24 items that are presented using 12 situations. Each situation contains two items. The first item requires the students to choose an answer and the second item requires the students to give reason which supports their answer. The test aims to assess students' reasoning ability which includes conservation, proportional thinking, identification, and control of variables, probabilistic thinking, correlative thinking and hypothetic-deductive ability. The instrument has well-established validity and reliability. Lawson, Banks and Logvin (2007 in Schen, 2007) performed a posttest Kuder-Richardson 20 internal-consistency and obtained a reliability coefficient of .79.

Teaching Approaches

A total of twelve lesson plans were prepared and implemented by the researcher for each of the two groups. Both classes were exposed to similar instructional activities such as demonstrations, discrepant events, magic tricks, group problem solving, laboratory activities. They were also administered identical assessment tools (i.e. quizzes, long exams, problem solving activities). The teacher-researcher ensured that each class got the same contact time for every lesson.

Students from both groups were also assigned team roles for every group tasks. The team roles were the following: facilitator, critic/time keeper, recorder, resource manager, and reporter. The team roles rotated for every group task so everyone was able to experience taking all the roles.

Student-Designed Inquiry (SDI)

The study involved the intervention called Student Designed Inquiry (SDI), which was composed of three sub-instructional activities namely, Inquiry Activity, Processing and Evaluation. The sequence of instructional activities is shown in Figure 1.

During the inquiry activity, each group of five to six students performed a laboratory activity. Accompanying this laboratory activity was an Inquiry Guide that contains the step-by-step approach in designing a laboratory procedure that is represented by the acronym PROBE, which stands for Prepare, Record, Organize, Break down, and Establish. Using the inquiry guide, SDI students were expected to: (1) PREPARE the materials needed for the investigation and the set of procedures to undertake; (2) RECORD observations and data; (3) ORGANIZE data into statements and mathematical expressions and models; (4) BREAK DOWN and analyze the results, take note of errors and limitations of the design; and (5) ESTABLISH conclusions and generalizations.

Each SDI group followed the PROBE-guide in designing and implementing procedures to answer a question in the laboratory activity. These questions were not included in the laboratory activity performed by students in the conventional group. In contrast, for each laboratory activity of conventional teaching approach (CTA), a step-by-step procedure was provided to each group. SDI students made their own sets of procedures together with their group mates. The groups decided which materials to use for each activity. However, to prevent possible delays, materials used by the groups were found on the set provided by the teacher. The SDI groups also decided the sequence while the conventional group followed a set of well-defined procedure. **The outcome and results for the conventional group were expected while the SDI group might or might not get the appropriate procedures and results**. For the first two activities, the teacher provided prompts in the form of questions addressed to the group that aimed to fine tune their ideas and redirect them to generate a more acceptable experimental design. The prompting also ensured that the groups work more independently, with very minimal scaffolding from the teacher on the succeeding activities.

The second component of the SDI was the Processing phase. During this phase, the reporter of each group discussed the concepts that had been developed through the laboratory activity, as well as presented the experiment that his/her group had designed. Moreover, the whole class took part in evaluating the experimental design and critiquing the results that had been presented by each group. There were instances in which the groups had different experimental designs. These gave the groups chance to compare their works, suggest ideas, point out errors in the design of the experiment and misconceptions, recognize the good points made or support the ideas raised by the presenting group. The students essentially led the class while the teacher listened and noted the concepts that had already been discussed during the presentation. To manage the use of the class time efficiently, the presentations, all in all, were limited to 30 minutes to make way for teacher inputs and other clarifications. Furthermore, the teacher reduced redundancy during discussion by clustering groups with similar components in their experimental designs (e.g. materials and procedure, results). The groups were also asked to highlight only those that they found unique to their design, such as, efficient way of gathering data; systematic style of communicating results; pattern arising from the data; and alternative conclusions that the group had generated.

The output of each SDI was evaluated on two aspects, namely, the experimental design and the contribution of each member. For evaluating the experimental design presented by other groups, a rating form was used. It was filled up collectively to save time and to involve all the members. On the other hand, the contribution of each member to the group output was assessed by students individually using a group work rating form.

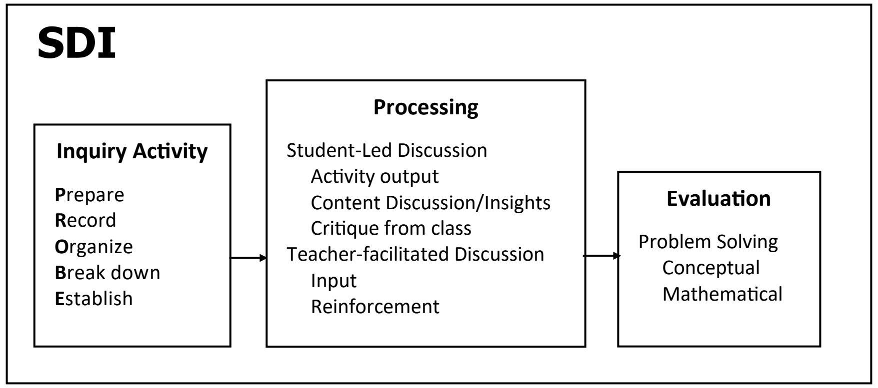

***Figure 1**. Sequence of SDI instructional activities*

After the presentation and critiquing parts, the teacher summarized the physics concepts using prepared presentation slides and also gave reinforcements regarding the output of the students.

The last component of the SDI was the evaluation part, in which students were required to answer either mathematical or conceptual problems. All the problems and examples used in the SDI class were similar to the problems used in the CTA class.

Conventional Teaching Approach

Each session of CTA began with a motivational activity similar to the SDI group. After engaging the students, the teacher presented a cookbook type laboratory activity. The teacher prepared the worksheet, materials, procedures and guide questions for the activity. Basically, the students followed teacher directions to come up with a specific concept or product.

The laboratory activity took one class session. The discussion of the results and related physics concepts was facilitated and led by the teacher the next day. The teacher explained each phenomenon that had been observed by the students in the activity. After the discussion, the teacher presented problems and modeled the step by step solution to the problems. The students were given individual exercises to assess their mastery of the topic. The instructional model used in this approach is 5E which also promotes inquiry-based learning. While the two teaching approaches are considered inquiry-based, the approaches differ in the degree of students' involvement with SDI leaning towards the side of student-directed and student-centered inquiry (Table 2).

Data Collection Procedure

The actual experiment started in the second quarter of Academic Year 2012-2013 at a laboratory school. The researcher used intact groups. To determine which class would be the SDI and CTA group, toss coin was used. The pretest using the Conceptual Understanding Test and Classroom Test of Reasoning Skills was administered on the first and second day of classes. The instructional phase started on the third day and lasted ten weeks. After which the posttests were administered. Selected groups were randomly chosen for audio recording of students' discussion during the inquiry activity and the processing phases.

Data Analysis Procedure

Two-tailed test t-test for independent samples was performed on the mean pretest scores of both groups in the Conceptual Understanding Test in Physics and Lawson's Classroom Test of Scientific Reasoning to determine whether the two groups are comparable before the intervention. One-tailed t-test for independent samples was used to compare the mean posttest scores of both groups in the Conceptual Understanding Test in Physics and Lawson's Classroom Test of Scientific

***Table 2**. Comparison of SDI and CTA*

SDI	Engage	Engage	**Conventional**
	Inquiry Activity	Explore	
	Process	Explain	
		Elaborate	
	Evaluate	Evaluate	

Reasoning. Simple linear regression was used to determine whether scientific reasoning is a significant predictor of conceptual understanding. Two-way ANOVA was used to determine whether the teaching approach and scientific reasoning affect conceptual understanding. Post hoc comparison using Scheffe test was carried out to determine which pairs cause the significant reasoning ability difference with respect to conceptual understanding. Mann-Whitney U test was used to compare high- and low-performing students' mean scores in the Conceptual Understanding Test in Physics. The Normalized gains in the Conceptual Understanding Test in Physics and Lawson's Classroom Test of Scientific Reasoning were also calculated.

Results

Student-Designed Inquiry and Scientific Reasoning

There was no significant difference between the pretest mean scores, t(58) = -1.24, p =.21 (Table 3). The results indicate that the two groups were comparable in terms of scientific reasoning prior to the experiment.

Effects of SDI on Scientific Reasoning

To determine if there was a significant difference in the scientific reasoning between the SDI and CTA, a one-tailed independent samples t-test was performed on their mean scores in the LCTSR posttest. Table 4 summarizes the results of this test.

The SDI group had numerically higher mean (M=15.10, SD=5.39) in the posttest than the CTA group (M=14.20, SD=4.44). But this difference was not significant as shown in Table 4, t(58) = -0.71 with p > 0.05. Therefore, there was no significant difference between the two groups on scientific reasoning after the experiment. The results of the study agree with the findings of Lawson and Jensen (2011) when they investigated the effects of instructional methods on reasoning gains. One section was taught using the inquiry method and the other section using a traditional style of didactic teaching. Results from their study showed no significant difference between inquiry and didactic sections for overall reasoning gains.

In order to probe further on the effectiveness of SDI in improving scientific reasoning, students in both groups were classified into: students with high reasoning ability (with scores 15 and above), average reasoning ability (with scores between 9 and 14), and low reasoning ability (with scores 8 and below) based on Lawson and Jensen (2011).

***Table 3**. t-test for Equality of Means on LCTSR Pretest Scores*

	Mean Difference	SE Difference	df	T	Sig (2-tailed)
Equal variances assumed	-1.00	1.247	58	-.802	.426
Equal variances not assumed	-1.00	1.247	55.649	-.802	.426

Note: SE = Standard Error

***Table 4**. t-test for Equality of Means on the LCTSR Posttest Scores*

	Mean Difference	SE Difference	df	t	Sig (1-tailed)
Equal variances assumed	-.900	1.276	58	-.706	.242
Equal variances not assumed	-.900	1.276	55.965	-.706	.242

Table 5 shows the percentage of students that belong to each subgroup before and after treatment.

The increase in the percentage of students belonging to 'high reasoning ability' in the CTA group is just equal (in fact 0.1% higher) to that of the SDI group. For the group exposed to SDI, the amount of the increase in the percentage of students under high reasoning ability group came from the group of with average reasoning ability and less from the group with low reasoning ability while in the case of CTA group, approximately 13% came from the group with average reasoning ability and the rest (approximately 10%) came from the 'low reasoning group'. The results show that SDI approach did not affect much those in the lower group and CTA seems to be more effective because it was able to impact (almost equally) all groups of students.

To further examine whether there was improvement in the scientific reasoning of the students after the treatment, a t-test for related samples was used to compare the mean pre- and posttest scores of each group in the LCTSR. The test showed that there was a significant difference in the scientific reasoning of both SDI and CTA groups before and after the treatment (Table 6). This indicates that although the treatment had a positive effect on the scientific reasoning of SDI students, the CTA students also benefited from the kind of instruction they were exposed to.

The analysis on the effect of SDI on students' scientific reasoning is extended by investigating its influence on the sub-components of scientific reasoning. Table 7 shows the test on the significance of the difference between mean pretest and posttest scores of SDI students in each component of the LCTSR. The test showed that there was a significant difference between the mean pretest and posttest scores in two components, namely, conservation of mass and volume, and control of variables. This result confirms that the SDI activities (a) helped the students to transition to late concrete or early formal-operational stage and (b) that required students to design their own experiments which entailed identifying the materials relevant to their inquiry, as well as, controlling variables of the laboratory activity significantly enhanced the component of scientific reasoning (control of variables).

Student-Designed Inquiry and Conceptual Understanding in Physics

***Table 5**. Percentage of students with high ,average and low reasoning ability for SDI and CTA groups*

Reasoning Ability	SDI		CTA	
	Pretest	Posttest	Pretest	Posttest
High	46.7	70.0	33.3	56.7
Average	26.7	10.0	43.3	30.0
Low	26.7	20.0	23.3	13.3

***Table 6**. Test of Change in the LCTSR Pretest and Posttest Scores*

		Mean Gain	Std. Dev	Std. Error Mean	t	df	Sig (2-tailed)
SDI	post-pre	1.700	2.231	0.407	-4.174	29	0.000*
CTA	post-pre	1.800	2.552	0.466	-3.864	29	0.001*

*p<.05

Table 7. Test of Change in the LCTSR Pretest and Posttest Scores per Scientific Reasoning Component

Component of Scientific Reasoning		Mean Gain	Std. Dev	Std. Error Mean	T	df	Sig (1-tailed)
Conservation of Mass and Volume	post-pre	0.48	1.04	0.19	-2.454	29	.010*
Proportional Thinking	post-pre	0.23	1.30	0.24	-0.980	29	.167
Control of Variables	post-pre	0.47	1.50	0.27	-1.701	29	.05*
Probabilistic Thinking	post-pre	0.03	0.72	0.13	-0.254	29	.400
Correlational Thinking	post-pre	0.23	1.01	0.18	-1.270	29	.107
Hypothetico-deductive reasoning	post-pre	0.37	1.22	0.22	-1.650	29	.055

*p<.05

As can be seen in Tables 8 and 9, the SDI group obtained a slightly higher mean (M=12.43, SD=3.66) in the pretest than the CTA group (M=11.43, SD=2.50) but both groups scored less than the passing mark of 17.5 points. However, this difference was not significant, t(58) = -1.24, p = 0.111. The results indicate that the two groups were comparable in terms of conceptual understanding at the start of the treatment.

Effects of SDI on Conceptual Understanding

Table 10 shows the means and standard deviations of the conceptual understanding posttest scores. The mean scores of the two groups were higher than the passing score of 50% (17.5).

To determine if there was a significant difference in the conceptual understanding between the SDI and CTA groups, a one-tailed independent samples t-test was performed on their CUT mean posttest scores. Table 11 summarizes the results of this test.

The mean posttest score of students who were exposed to SDI (M=23.3, SD=6.39) was numerically higher than the mean posttest scores of students who were exposed to CTA (M=22.8,SD=4.92). However, this difference was not significant, t(58) = -0.385, p =.351. This result suggests that SDI is just as effective as CTA in improving students' conceptual understanding in physics.

When Cobern et al. (2009) conducted an experimental study to compare inquiry-based and direct instructions, they found that students from both groups acquired comparable conceptual understanding of science subject matter. According to them, the results were not surprising and reasonable for a number of reasons: first, they employed well-designed units that were based on acceptable models of good teaching for both modes; second, the lessons contained "generic" instructional features that were common to both modes; third, both groups experienced "hands-on" activities; and lastly, the application phase which was present in both modes tend to even out differences in initial concept learning.

The reasons offered by Cobern et al. (2009) echo the explanation for the non-significant result in this study. Both SDI and CTA groups performed hands-on experiments that dealt with similar problems and were required to identify the same physics-related concepts after the activity. Only in SDI, there were parts where the students were obliged to design their own procedures and make plans and think of appropriate conclusions (PROBE). It is possible that although they learned from the activity, it was not fully absorbed nor retained because the SDI posed greater cognitive demand on the students.

Table 8. Means and Standard Deviations of Conceptual Understanding Pretest

Group	N	Mean	SD	SE
SDI	30	12.43	3.66	.67
CTA	30	11.43	2.50	.46

Note: CUT Perfect Score = 35

Table 9. t-test for Equality of Means on the Conceptual Understanding Pretest Scores

	Mean Difference	SE Difference	df	t	Sig (2-tailed)
Equal variances assumed	-1.00	0.810	58	-1.24	.222
Equal variances not assumed	-1.00	0.810	51.20	-1.24	.223

Note: SE = Standard Error

Table 10. Means and Standard Deviations of Conceptual Understanding Pretest

Group	N	Mean	SD	SE
SDI	30	23.3	6.39	1.17
CTA	30	22.8	4.92	.898

Note: CUT Perfect Score = 35

Table 11. t-test for Equality of Means on the Conceptual Understanding Pretest Scores

	Mean Difference	SE Differenc e	df	t	Sig (1-tailed)
Equal variances assumed	-.567	1.47	58.0	-.385	.351
Equal variances not assumed	-.567	0.810	54.43	-.385	.351

Note: SE = Standard Error

The disruptions (e.g., class suspensions and school activities) during the intervention resulted to the SDI group being one activity behind the CTA group. There were also instances where the SDI group had to reconstruct their experimental designs and rethink their ideas because most of them were too exhausted to focus on the tasks they were asked to perform.

Furthermore, the SDI student had grown weary of doing PROBE almost every week. This was evident in the students' entries in their weekly learning matrices. A closer inspection of the responses of SDI students reveals that students generally held a negative disposition towards doing PROBE. They only wanted to finish the activity because they were required to submit their outputs on time.

The non-significance may have also been caused by the resistance of students exposed to SDI to additional challenges presented by the instructional method. Many students regarded the aspects of PROBE easy but nonetheless expressed general dislike to a new method. Brickman et al. (2009) offered a possible explanation to this behavior by suggesting that this might stemmed from the "increased demand from them to learn in a new and more rigorous way".

The result of the this study also validates that of Loughran and Derry (1997 in Brickman et al, 2009) which reported that students do not like the additional burden of thinking through the problems given to them. In the case of SDI, some students expressed their frustrations for not being able to: design procedures (SDI25); come up with accurate results (SDI23); obtain sensible data to be analyzed (SDI22); and make plausible conclusions (SDI10). These students might have developed dependence to highly structured laboratory activities and are accustomed to being provided with details and procedures on how to do an investigation.

Aside from the perceived difficulty of executing PROBE, some students were dissatisfied with group members who neglected their responsibilities and tasks, despite their team roles. There were instances when group focus declined because some members began to do things that were not relevant to the assigned task. This led to more problems like mediocre outputs, frustration and more confusion. However, this problem was felt by both SDI and CTA students and was evident in their learning matrices entries.

Effect of Teaching Approach on High and Low Performing Students

To distinguish the effect of the teaching approach on high- and low-performing students in each group, the CUT posttest scores were ranked to identify 10 high-scorers and 10 low-scorers. A one-tailed Mann-Whitney U test for independent samples was conducted to the compare the conceptual understanding of high- and low-performing students from both groups (Table 12).

The results show that there was a significant difference in the CUT mean posttest scores of high-performing students exposed to SDI with mean rank, 13.20 and high performing students from the CTA with mean rank, 7.80; U = 23.0, p =.022. However, there was no significant difference in the CUT mean posttest score of low-performing students exposed to SDI (mean rank =10.25) and CTA (mean rank=10.75); U = 47.5, p = .427. This suggests that high- performing students exposed to SDI have higher conceptual understanding compared to their counterparts in the CTA. Moreover, the results imply that SDI is effective in improving the physics concept understanding of high-performing students. It also connotes that SDI tends to be biased towards and caters only to high-performing students than low-performing students.

***Table 12**. Independent Samples Mann-Whitney U Test on Conceptual Understanding of High- and Low-Performing Students*

	N	Mean Rank	Sum of Ranks	U	Sig. 1-tailed
		High-Performing Students			
SDI	10	13.20	132	23.0	.022*
CTA	10	7.80	78		
Total	20				
		Low-Performing Students			
SDI	10	10.25	103	47.5	.427
CTA	10	10.75	108		
Total	20				

Another way to determine the effect of each teaching approach on conceptual understanding is by calculating the normalized gain <g> for each group. The normalized gain , <g>, is given by the equation

<g> = (<posttest score> - <pretest score>/ (maximum score - <pretest score>)

The normalized gain of each of the identified high and low performing students was computed (Table 13). For the high-performing students, the SDI group had a higher normalized gain, <g>SDI high = 0.75 that is considered as high gain compared to CTA group, <g>CTA high = 0.69, which is considered as medium gain. However, low-performing students from CTA had higher normalized gain, <g>CTA low = 0.30 that is considered as medium gain compared to students exposed to SDI, <g>SDI low = 0.24, which is considered as low gain. These results further support the previous discussion that SDI tends to be biased towards high-performing students over those who are low-performing. With this, we can say that SDI can be more effectively implemented in high schools with special science curriculum or in high schools with academic honors sections.

The positive effect of scientific reasoning on conceptual understanding agrees with the previously published results of Lawson and Johnson (1998) that demonstrated that reasoning ability is a predictor of achievement and a strong predictor of success in college biology. It is common in physics to include conceptual understanding and problem solving skills as subcomponents of achievement (Monterola, 2012 ; Ates &Cataloglu, 2007) The results of this study also validate the claim of Pyper (2011) that there is a strong correlation between reasoning and understanding.

Scientific Reasoning as Predictor of Conceptual Understanding

Simple linear regression analysis (Table 14) was used to determine whether scientific reasoning significantly predicts conceptual understanding. The posttest scores in conceptual understanding were subjected to simple linear regressions with scientific reasoning posttest scores as the predictor variable.

The model for the simple linear regression describes scientific reasoning as the predictor and conceptual understanding as the dependent variable. The R-value of .426 represents a positive but modest correlation between scientific reasoning and conceptual understanding. About 18.2 % of the variation in the CUT posttest scores can be statistically accounted for by scientific reasoning. The results of the analysis of variance show that the regression model for scientific reasoning significantly predicts conceptual understanding scores, R2 = 0.18, ΔR2 = 0.18, F (1,58) = 12.87, p =0.001. The linear regression equation for conceptual understanding (CUT) score in terms of the scientific reasoning (LCTSR) score is:

CUT score = 15.866 +0.490 (LCTSR score)

The positive effect of scientific reasoning on conceptual understanding agrees with the previously published results of Lawson and Johnson (1998) that demonstrated that reasoning ability is a predictor of achievement and a strong predictor of success in college biology. It is common in physics to include conceptual understanding and problem solving skills as subcomponents of achievement (Monterola, 2012 ; Ates &Cataloglu, 2007) The results of this study also validate the claim of Pyper (2011) that there is a strong correlation between reasoning and understanding.

***Table 13**. Normalized Gain in Conceptual Understanding of High- and Low-Performing Students*

	High-performing	Low-performing
SDI	0.75 (High Gain)	0.24 (Low Gain)
CTA	0.69 (Medium Gain)	0.30 (Medium Gain)

Scientific Reasoning as Predictor of Individual Normalized Gain in Conceptual Understanding

To investigate further whether students' initial

Table 14. *Simple Linear Regressions on Conceptual Understanding Test Posttest Scores Using Classroom Test for Scientific Reasoning Posttest Scores as*

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.426	0.182	0.167	5.166

Note: The predictors are constant and scientific reasoning

ANOVA Results

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	343.3	1	343	12.9	.001*
	Residual	1547	58	26.7		
	Total	1891	59			

Coefficients

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	15.866	2.111		7.516	.000
	Scientific Reasoning	0.490	.137	.426	3.587	.001*

scientific reasoning positively predicts the individual normalized gain in concept understanding, LCTSR pretest scores and normalized gain, <g>, in CUT were subjected to simple linear regressions with LCTSR pretest scores as the predictor variable (Table 15).

The R-value of .437 indicates a positive but modest correlation between scientific reasoning and gain in conceptual understanding. The table shows that about 19.1 % of the variation in the CUT normalized gain can be statistically accounted for by scientific reasoning pretest scores. The results of the analysis of variance in Table 28 show that the regression model for scientific reasoning significantly predicts normalized gain in conceptual understanding, R2 = 0.19, ΔR2 = 0.18, F(1,58) = 13.71, p <.001.

The linear regression equation for normalized gain in CUT in terms of the scientific reasoning (LCTSR) pretest score is:

CUT <g> = 0.230 + 0.020 (LCTSR pretest score)

The result of this study is also consistent with that of Coletta and Phillips in 2004 which have established a strong correlation between normalized gain in the Force Concept Inventory (FCI) and pre-instruction scores in Lawson's Classroom Test of Scientific Reasoning (LCTSR). In the same way, Moore and Rubbo (2011) observed a similar strong correlation between pre-instruction LCTSR scores and normalized gain in two concept inventories, the Determining and Interpreting Resistive Electric circuits Concept Test (DIRECT) and the Test for Understanding Graphs-Kinematics (TUG-K).

Differences in Conceptual Understanding for Students with High, Average, Low Reasoning Ability and Teaching Approach

To investigate whether there are differences in conceptual understanding for students varying in scientific reasoning ability (high, average, low) and kind teaching approach (SDI and CTA), two-way ANOVA was used. In this analysis, the teaching approach and levels of scientific reasoning based on LCTSR posttest scores were considered as independent variables, while CUT posttest scores were considered as the dependent variable.

As presented in Table 16, the difference in physics conceptual understanding is only statistically significant with respect to scientific reasoning but not with the teaching approach. Moreover, the results show that there is no significant interaction between the teaching approach and scientific reasoning ability. Examining students' CUT posttest scores with respect to their scientific reasoning ability revealed that students with higher scientific reasoning ability had higher conceptual understanding.

Table 15. *Simple Linear Regressions on Normalized Gain in CUT Using CTSR Pretest Scores as Predictor*

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.437	0.191	0.177	0.199

Note: The predictors are constant and scientific reasoning pretest scores

Coefficients

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.543	1	0.543	13.712	.000*
	Residual	2.298	58	0.040		
	Total	2.842	59			

Model

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	0.230	0.074		3.111	.003
	CSTR Pretest	0.020	0.005	.437	3.703	.000*

Post hoc comparison using Scheffe test was carried out to determine which pairs cause the significant conceptual understanding difference with respect to reasoning ability. As Table 17 shows, there was a significant difference between groups with high and low reasoning ability mean CUT scores (p =.003) and between groups with high and average reasoning ability (p =.025) while there was no significant mean difference between groups with low and average reasoning ability (p =.730).

Sungur et al. (2001) reported a significant difference only between groups with high and low reasoning ability (formal vs. concrete -operational) while this study showed additional significant difference between groups with high and medium reasoning ability.

Conclusions

Based on the results, the study arrived at the following conclusions:

1. Student-Designed Inquiry is effective in improving conceptual understanding of high-performing students and in developing students with high reasoning ability.
2. Scientific reasoning is a significant predictor of conceptual understanding in physics.

Recommendations

For Teachers

1. Student-Designed Inquiry will provide variety and can improve conceptual understanding and scientific reasoning but must be used in moderation over a long period of time to prevent fatigue and saturation.
2. Assess the reasoning abilities of students to enable them to identify who are at risk. Teachers should be aware of the reasoning ability of their students and **design the lesson accordingly**.

Table 16. *Two-Way Analysis of Variance for Physics Conceptual Understanding as a Function of Scientific Reasoning and Teaching Approach*

Variable and Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Teaching Approach	11.206	1	11.206	0.430	.515
Scientific Reasoning	392.008	2	196.044	7.529	.001*
Teaching Approach* Scientific Reasoning	41.721	2	20.860	0.801	.454
Error	1406.070	54	26.038		

Table 17. *Multiple Comparisons of Concept Understanding as a Function of Scientific Reasoning*

Reasoning Ability	Reasoning Ability	Mean Difference	Std. Error	Significance
High	Low	6.48	1.814	.003*
	Medium	4.75	1.690	.025*
Medium	Low	1.73	2.185	.731
	High	-4.75	1.690	.025*
Low	Medium	-1.73	2.185	.731
	High	-6.48	1.814	.025*

**p<.05*

3. Make scientific reasoning explicit by designing instructional materials that develop scientific reasoning which can increase gains in LCTSR and conceptual inventories/tests.

For Policy-makers, Curriculum Developers and School Administrators

1. In utilizing this type of teaching approach that highlights inquiry, schools must ensure support to the changes in the curriculum, instruction and assessment by providing workshops and professional development for teachers.
2. Teachers and other professionals involved in curriculum development can take advantage of opportunities to allow students to generate and test hypotheses or to at least design experiments.
3. Incorporate the development of scientific reasoning in the curriculum to be able to produce scientifically literate individuals.

For Researchers

1. The study lasted for only 10 weeks. It can be replicated by carrying out the experiment for one academic year where the Student-Designed Inquiry is used regularly without saturating the students (i.e., twice per unit of lesson).
2. Future research should take into consideration the inquiry levels of the experimental and conventional group in comparison. The Student-Designed Inquiry group must possess higher inquiry compared with the teaching approach used by the conventional group (i.e., direct instruction, lecture class with very minimal laboratory experience).
3. Future research can include the use of group task performance or actual assessment in addition to pencil and paper tests.
4. Future research can look into the effects of Student-Designed Inquiry to other learning outcomes such as science process skills, higher-order thinking skills, self-efficacy and attitude.

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