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Comparing the Effects of Cookbook and Non-Cookbook Based Lab Activities in a Calculus-Based Introductory Physics Course

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Abstract

I have compared the effects of Cookbook based lab activities with the impacts of doing lab inquiry based on a small introductory engineering physics course. Performance in lab activities that did and did not require the Cookbook procedure was compared using a final questionnaire from the participating students in that course. The population of students who did the lab in each scenario was the same because they enrolled in the same course. In the course, I planned five lab activities of three different types. The first type, which I call "Cookbook" activities (CB) were prepared and then completed by students. The second type of activities, which I call" Non- Cookbook" (NCB) were inquiry-based and orally guide. The final activity type was called "Both" and was a combination of two other activities. I investigated the activities in two dimensions: "scientific skills" and "general skills". The results for scientific skills showed in NCB "Predicting" have improved. In CB, "Measuring the quantity" and "Sorting/classifying" have positive points of improving scientific skills. For general skills, in NCB, "Recalling concepts" and "Conceptual understanding" were improved. In CB, "Conceptual understanding" and "Scientific writing skills" and "Self-efficacy" were improved. "Writing the lab report" is a tough skill in NCB, while it is easy for CB.

Keywords

introductory calculus-based physics, cookbook, lab activates, non-cookbook

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Introduction

The idea of conceptual understanding of physics has been affected the teaching process. The recommendations of the physics education community and national education documents also encouraged the instructors to move beyond traditional teaching methods (NGSS Lead States, 2013). To achieve to a conceptual understanding one way is paying attention to the combination of teaching techniques and lab activities in an active environment. Physics education research have shown during lab activities, students' active participation in the research process will also enhance their learning and labs have more positive effects on teaching when instructors use them as additional resources to have experimental practice, not just to teach the content (Evrim, 2016). Seyed Fadaei et al., (2013) mentioned the instructors have been informing about the benefits of labs and scaffolded procedures to achieve to the conceptual learning and Holmes et al., (2018) mentioned how effective labs are examining at achieving various goals and they are enhancing students' quantitative critical thinking skills, Etkina (2015) is focusing on exploring students' scientific abilities and Kozminski et al., (2014) mentioned the students' engaging in scientific practices. Amerine et al., (1988) discussed in all activities for interactive-engagement, discovery labs, how one should proceed, what is important to focus, what is relation between important concepts and what is not.

"Sometimes, lab work in science education is divided into two opposite types. On the one hand, there are traditional lab activities where students' actions are specified in a step-by-step manner and where a typical goal is to show the correctness of a certain textbook equation. Some authors and educators therefore use the name cookbook labs to characterize them" (Domin, 1999, Leornad, 1991, Lochhead et al., 1981, Roth, 1994, Trumper, 2003). On the other hand, "there are labs whose design is informed by the progressive and student-centered ideology that has dominated education in many countries in recent decades. These labs, which are sometimes described as discovery labs or open inquiry, are characterized by reference to the students' active engagement and exploratory investigations" (Domin, 1999, Leornad, 1991).

Cookbook (CB) Lab Activities

The majority of auxiliary materials provided with any textbook includes a large number of labs that have step-by-step instructions. "Cookbook labs are often criticized, as it is argued that, "when students are regimented by lab manuals that dictate what to think, how to think, and when to think, lab activities essentially lose impact for learning." (Pushkin, 1997, p. 240). Although it is important in science for students to learn how to follow directions, offering only prepared procedure labs limits students' access to exploration. A worthwhile goal of a science teacher is to allow students to think and behave like scientists rather than to solely learn or replicate what other scientists have already done. "Recipe-like activities often short circuit opportunities to stimulate thinking by students" (Germann et al., 1996). "Cookbook labs involve excessively detailed instructions that allow students to follow a recipe without having to think about what they're doing" (Royuk et al., 2003). In this type of lab activities students often, do not see a big concept of what they are trying to convey. Students read each step discretely and do not connect the steps to see the bigger intention of the laboratory experience. "The CB style experiments are conducted followed by written instructions without any oral procedure" (Royuk, 2002). "Students have difficulty constructing meaning from CB labs, but inquiry-based labs require the ongoing intellectual engagement of the students" (Peters, 2005). "This is often pointed to as a general problem with student centered and inductive approaches, and it is argued that the appealing

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pedagogical ideas of making students active learners and young scientists seem to be difficult to achieve in practice" (Edwards et al., 1987, Hodson, 1990).

Non-Cookbook (NCB) Lab Activities

The kind of lab work that has been investigated in this paper is often put forward as the alternative to Cookbook labs and unstructured discovery labs. The characteristics of the alternative, and what makes it different from other activities, are suggested in names such as "interactive engagement" (Hake, 1998, Royuk, 2002), "guided discovery" (Ausubel, 1968, Novak, 1979), and "computer supported inquiry learning" (van Joolingen et al., 2007). These activities are called Non-Cookbook (NCB) laboratory activities are typically very different from other components of a class (lecture and recitation). They last longer, are self-paced and require students to work in groups to complete a task. All of these things make it important for students to be metacognitive about their activities during lab. In NCB, teachers search actively and participate in inquiry-based laboratory experiments instead of CB style experiments. In this case study, I started with two NCB activities at the beginning of the quarter. However, based on students' request I continue the lab with two CB activities and at the end of the course with a combination of two NCB and CB activities which I call it "BOTH". For scoring the reports of all these activities, I created a rubric on Canvas.

Research Questions

I conducted this study with the following research questions:

1-Cognitive idea to recognize the types of equipment and procedure of CB and NCB lab activities: What factors did students mention?

2-Metacognitive understanding of students in the process of scientific skills in both types of lab activities: What benefits and challenges did students mention?

3-Other skills improvement for both types of lab activities: What benefits and challenges did students mention?

The research method: Action research

"Action research, as a practitioner-oriented inquiry, seeks to change instructional practices through planning the lesson, teaching the lesson plan, observing the implementation of the lesson, and reflecting on the teaching experience… Teachers-as-researchers ask questions, collect, reflect on, and evaluate data in ongoing cycles to better understand how they teach and how effectively their teaching methods help their students learn" (Altrichter et al., 2013). "Although action research methodology has the potential to change teaching practices, it has rarely been used in undergraduate science education" (Raubenheimer et al., 2005). In this paper, I investigate the experiences of an undergraduate physics laboratory instruction using action research, while implementing an instructional approach that incorporates scientific practices into students' learning process.

The environment of the study

This investigation took place within the context of lab activities in a calculus-based physics 221 course (7 hours per week) in winter quarter 2019 at the South Seattle College. The case study was a class with 22 students and implementation took 10 weeks. Students should be comfortable manipulating and solving algebraic (including quadratic) equations for a variable, solving systems of equations (e.g., finding the intersection of two lines), drawing and interpreting graphs, using ratios, and using trigonometric functions to find angles and sides of triangles, basic vector addition, subtraction, dot product, and cross product. Most of the concepts were planned to be taught in an active learning environment. Each session was planned to use demonstration or simulation or lab activities. For lab activities, I used five long activities, which were completed by students in their groups of three or four. In the classroom, students had access to computers and lab equipment. In addition, students had access to Logger Pro software and PHET. These two types of virtual equipment were not separated as traditional and non-traditional lab activities with CB or NCB. In both groups, I used active learning method and computer-based activities for real-time physics experiments using graphical analysis soft wares, probes, sensors, equipment and video analysis of Logger Pro and "ISLE Video Experiments" which were created by Etkina and Van Heuvelen (2007). For CB, the written guide and procedure, prepared questions, filling the tables for measurement results, and wrap up questions were used as template. For NCB, the oral guide and power point presentation and demonstration, scaffolding prepared questions presented in oral speech and discussions to answer the general idea of the experiment were used generally (**Figure 1**). For all lab activities, physical equipment and hands-on simulations together with analyzing software were used to investigate the results. In traditional teaching, the written guide and procedure as CB for physics lab activities is used. In NCB, which is called as new active learning using in lab, the students learn the concepts of physics, research and find new hypothesis related to physics phenomena by scaffolded questions to get motivated for creativity and arising deep knowledge to better understanding. Instructor has the role of a facilitator to guide them in this road. I investigated the students' thoughts about their skills' improvement comparing NCB and CB activities.

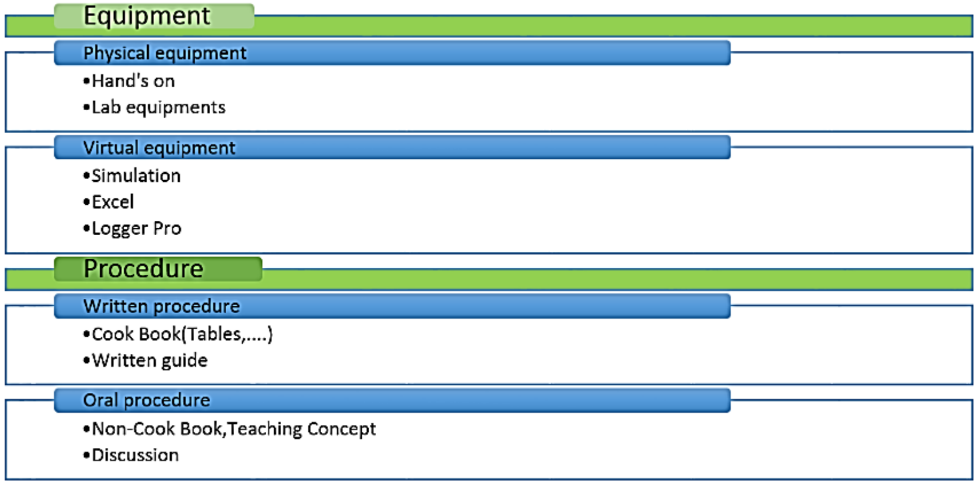

Figure 1. The category of lab equipment and procedures

Students were working in their groups, but for the lab report, everybody was expected to write it by her/himself. The lab activities had been done in the class environment. Due two weeks after each lab activity, students were expected to write the lab reports and submit them online on Canvas. The lab reports were scored using a rubric (made by me) and then I sent the grades online to the students. Therefore, students were aware of their work in written lab reports and their success in doing them. On the first lab report, after they prepared the demo, they went in the process of peer- review into the class environment in which they edited other students' lab reports to improve scientific writing. It was a type of metacognitive process for understanding, what is going on in lab activities' reports. This helps them to understand all parts of the rubric and what they were being asked for on the next lab activities. The process and the grade for lab reports showed they were improving in scientific writing and scientific thinking. The idea of what students did during the lab activities were: "Thinking like a scientist, Exploring and predicting, Posing a testable question, Designing experiments, Collecting data to answer a question, Interpreting data through graphs and identifying patterns, Sharing data as a research community (whiteboards), Engaging in evidence-based reasoning & argumentation when writing lab reports" (Bortner et al., 2018).

Tool of study

My investigation about comparing the effects of NCB and CB lab activities turned out to be more complicated than looking at exam or lab report scores. "Evaluating patterns in students' responses through cluster and network analysis will be useful in identifying related response choices within and across questions" (Walsh et al., 2019). Therefore, I planned a questionnaire with 16 questions including three categories (**Figure 2**):

- The first category was investigating students' understanding and ideas about the lab activity types: CB, NCB and BOTH.
- The second category was analyzing students' improvement in scientific skills.
- The third category was discussing students' improvement in general skills.

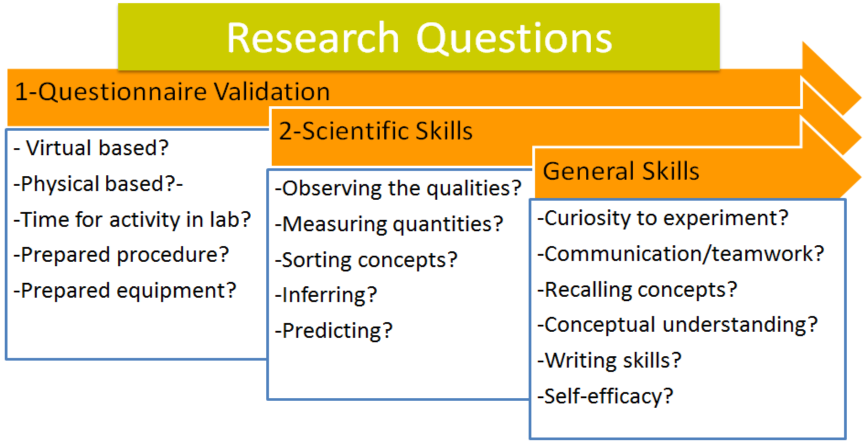

Figure 2. Three categories of research questions

Finally, I went back and characterized their answers according to the number of times students mentioned carrying out or not carrying out various thinking, or cognitive tasks, involved in doing authentic experimental physics in NCB and CB activities. Such tasks include "defining types of activities, equipment, and presenting their thoughts about scientific skills and other skills" (Wieman, 2015).

Discussion: Results from three categories of questions

First Category: Looking at student thinking

To try to understand what might be done to make lab activities more effective, I turned to the basic method underlying most physics education research: looking at student thinking. The data were collected through a survey given in an online form. "Students participating in the study, therefore, were ones who attended class and completed the survey on the day the survey was conducted" (Salehi et al., 2019). The student characteristics for each offering are summarized in **Table 1**. I explored that mental terrain through students' lab reports. Caused on students' feedback for the first and second lab reports, I decided to change the type of lab activities from NCB to CB. One of the students in his second lab report mentioned: "To improve further iterations of this lab experiment and all lab experiments, a standard lab procedure should be provided with clear concepts, objectives and steps to complete with probing questions along the way. Without a lab procedure, it is difficult to emphasize what is important to take away from the lab and apply meaningful lessons to further studies." The variety of ideas was very large. Students even wrote different titles for an experiment with no procedure (NCB)!

Table 1. The result of questionnaire in terms of students' cognitive idea to recognize the types of equipment and procedure

Type	No	Lab Activity Title	Physical equipment	Virtual equipment	Written procedure	Oral procedure	Rubric
NCB	1	Investigating the motion of a ball tossed upward	✓	✓		✓	✓
	2	Analyzing the collision of two cars	✓	✓		✓	✓
CB	3	Investigating gravitational potential energy of a ball tossed upward		✓	✓		✓
	4	Analyzing the motion of two objects in one dimension		✓	✓		✓
Both	5	Investigating Newton's Second Law	✓	✓	✓	✓	✓

This specific investigation focuses on whether the design of the lab activities (task, method, grading, topic, etc.) fosters "productive metacognition and sense-making" (Lippmann, 2005). To look at their thinking during the process of changing from NCB to CB lab activities, I planned the questionnaire and asked them some general questions about their experiences in scientific thinking and writing, such as (First type of questions): How much was the lab activity Virtual based? How much was the lab activity physical based? How much time did you spend in the laboratory (versus home)? How much did you use prepared procedure (like the cookbook!)? How much did you use prepared simulations, graphical and data analysis (Like Phet, Excel or Logger Pro)?

Results for the first category of questions related to investigating students' understanding and ideas about CB, NCB and BOTH are shown in Table 1. The purpose of the first part of the questions was the validation of the accuracy of students' answers to this questionnaire. In Table 1, I have divided the type of lab activities in different categories. By giving the students the questionnaire, I have evaluated their answer accuracy for the rest of the results in this study (see Figure 3).

Lab activity 1 and 2 were NCB with guided oral description and both physical and virtual equipment were used in them. In lab activity 3 and 4 I used CB and no oral description, also they were virtual activities based on computer software. In lab report 5, I mixed different types of activities.

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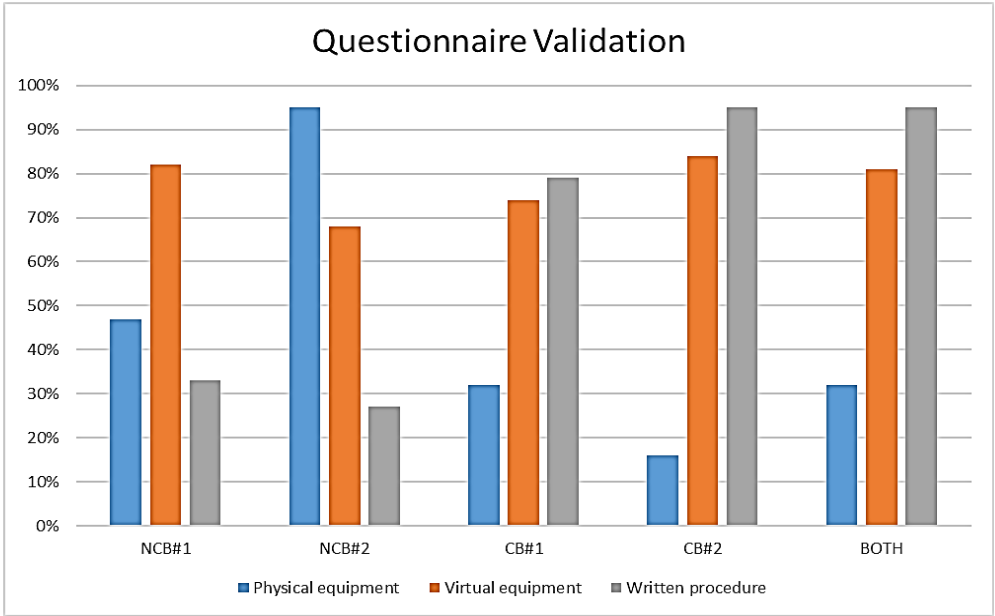

Figure 3. Investigating the accuracy of students' responses to questions regarding the category of lab activities

Note: The percentage shows more than average choices; for instance, 90% for physical equipment shows 90% of students at least chose average, above average or very high in their responses; therefore, 10% of the population chose below average and very low responses. This shows that some of the students did not get the aim of the question, or they did not have enough ability in metacognitive learning.

Lab activity 1 and 2 were NCB with guided oral description and both physical and virtual equipment were used in them. In lab activity 3 and 4 I used CB and no oral description, also they were virtual activities based on computer software. In lab report 5, I mixed different types of activities.

Investigating the accuracy of students' answers

As seen in **Figure 3** in lab reports NCB, most of students have chosen the physical equipment and the virtual equipment more than average. In lab reports CB, most of students have chosen the virtual equipment more than average. In addition, they have mentioned written procedures for lab reports CB. In lab report BOTH, some of students have chosen the physical equipment and most of them virtual equipment more than average. In addition, they have mentioned written procedure for lab report 5. The results comparing **Table 1**, depending on our planning are acceptable.

These results show the validation of this research depending on students' metacognitive learning and we can rely on the rest of the questionnaire results for getting more information.

Second Category of questions: Scientific skills

The purpose of the second part of the questions was metacognitive understanding of students in the process of scientific skills in lab activities. The questionnaire included:

How much did the lab activity improve your ability to observe the qualities? How much did the lab activity improve your ability to measure quantities? How much did the lab activity improve your ability to sort/classify concepts? How much did the lab activity improve your ability to infer? How much did the lab activity improve your ability to predict?

Investigating scientific skills

Results are shown in **Figure 4**. On all lab activities, students chose more than 50% average or above average for scientific skills. This shows the lab activities were successful in this part. For lab activities NCB, "Ability to infer" was the least. For lab activities, CB, "Ability to predict", "Being curious to experiment" and "Communicating, and teamwork" was the least. For lab activity BOTH, "Communicating and teamwork" were the least. As a wrap-up, for lab activities with NCB, the "Ability to infer" was the toughest part for students. This shows they could not understand the whole purpose and the things, which they should do in the experiment. On the other hand, they could not understand what they were expected to do. This means they do not have enough information on what they should do. Sometimes they were confused, and it is the exact thing happens for scientists in their research. "Students need to spend more time making their own decisions and learning from their choices." (Holmes et al., 2018). However, the "Ability to predict" and "Communicating and teamwork" as positive points were considerable. Giving students additional time to work on NCB activities will make them more successful and "…An extra hour can make to students' productivity" (Holmes et al., 2015). For lab activities with CB, "Ability to predict" and "Being curious to experiment" and "Communicating, teamwork" were the toughest part for students. This shows they could not get involved in the process of predicting and being curious in the activity and because they follow the CB, they do not need to improve their communication for doing the activity. However, the Measuring the quantities, Sorting/classifying concepts and communicating/teamwork as positive points were considerable.

For BOTH lab activity, with the combination of NCB for some part and CB for the other part of the activity, as I mentioned Both in this paper, "Communicating and teamwork" were the toughest part for students. However, the other parts of scientific skills as positive points were considerable.

The overall analysis of students' evaluation scores of lab reports for scientific skills (according to correspondence rubric for scientific skills) showed the higher percent grades belongs to "Predicting" and less percent grades belongs to "Ability to Infer" for NCB. In CB, the "Measuring the quantity" and "Sorting/classifying" have higher and "Predicting" has less percent grades than NCB. These scores confirm the final result of the survey.

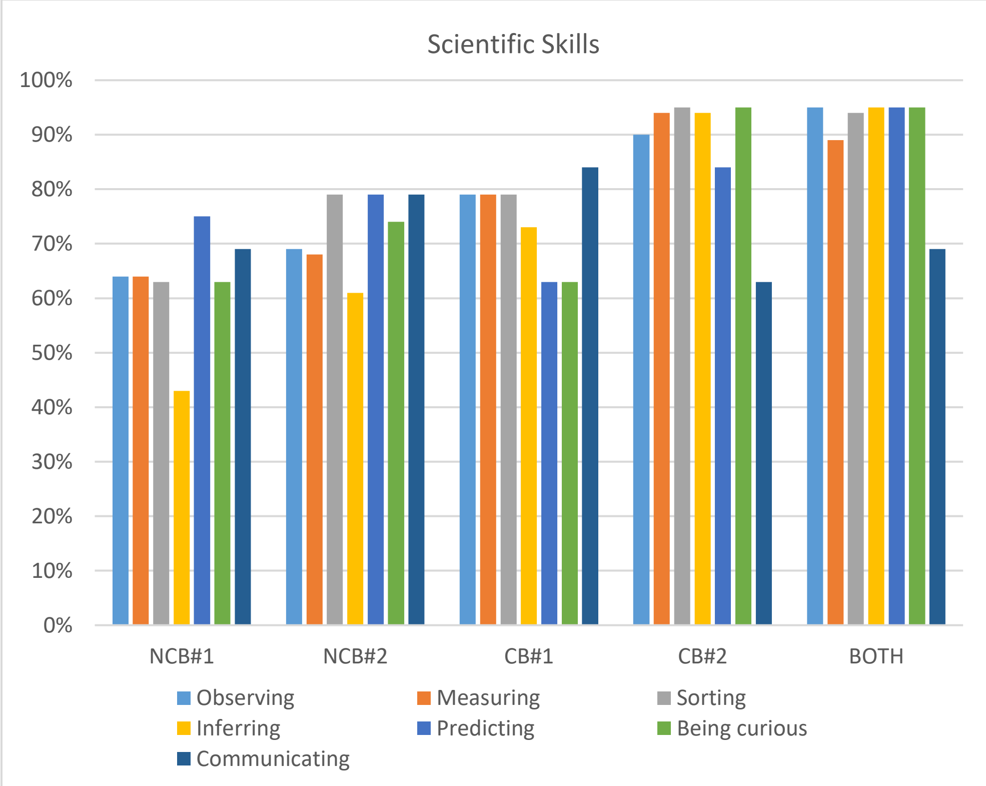

Figure 4. Survey results for improving the scientific skills
Note: The percentage shows more than average choices; for instance: 90%, shows 90% of students at least chose average, above average or very high in their responses

The questionnaire included:

- Observing: How much did the lab activity improve your ability to observe the qualities?
- Measuring: How much did the lab activity improve your ability to measure quantities?
- Sorting: How much did the lab activity improve your ability to sort/classify concepts?
- Inferring: How much did the lab activity improve your ability to infer?
- Predicting: How much did the lab activity improve your ability to predict?
- Being curious: How much did the lab activity motivate your curiosity to experiment?
- Communicating: How much did the lab activity improve your communication and teamwork?

Third category of questions: General skills

The purpose of the third part of the questions was investigating students understanding in their other skills improvement. In the end, we can achieve to the whole idea of their answers regarding types of lab activities and their percentage of success to help students to improve their knowledge. Finally, we can judge what kind of lab activities are more powerful in which part of aspects. This questionnaire included: How much did the lab activity motivate your curiosity to experiment? How much did the lab activity improve your communication and teamwork? How much did the lab activity improve your ability to recall concepts? How much did the lab activity improve your conceptual understanding? How much did the lab activity improve your scientific writing skills? How much did you feel comfortable to write the lab report? How much did the lab activity improve your Self-efficacy?

Investigating the improvement of General skills

Results are shown in **Figure 5**. As a wrap-up, for lab activities with NCB, the ability "Writing the lab report" was the toughest part for students. This shows they were not feeling good in writing lab reports without CB. However, the "Ability Recalling concepts" and "Conceptual understanding" as positive points were considerable. For lab activities with CB, the ability "Recalling concepts" was the toughest part for students. This shows they were not feeling good about their ability to recall the concepts for activities with CB. In addition, the abilities of "Conceptual understanding", "Self-efficacy" and "Scientific writing skills" are positive points. For lab activity BOTH, with the combination of NCB for some part and CB for the other part of the activity, called BOTH in this paper, there was not a tough part for students. All other skills as positive points in this type (all are more than 95%). This activity was the last one and at the end of the quarter, students were professional in writing lab reports. They were skilled enough to work with CB and NCB activities and their abilities in different parts improved.

The overall analysis of students' evaluation grade of lab reports for general skills (according to correspondence rubric for general skills) showed the higher percent grades belongs to "Recalling concepts" and "Conceptual understanding" and less percent grades belongs to "Inferring" and "Preparing lab reports" for NCB. In CB, it showed higher percent grades belongs to "Conceptual understanding" and "Scientific writing skills" and "Self-efficacy" than NCB. On the other hand, "Conceptual understanding" and "Predicting" and "Being curious to experiment" and "Recalling concepts" has less percent grades than NCB. This comparison showed the reliability of the results in this survey.

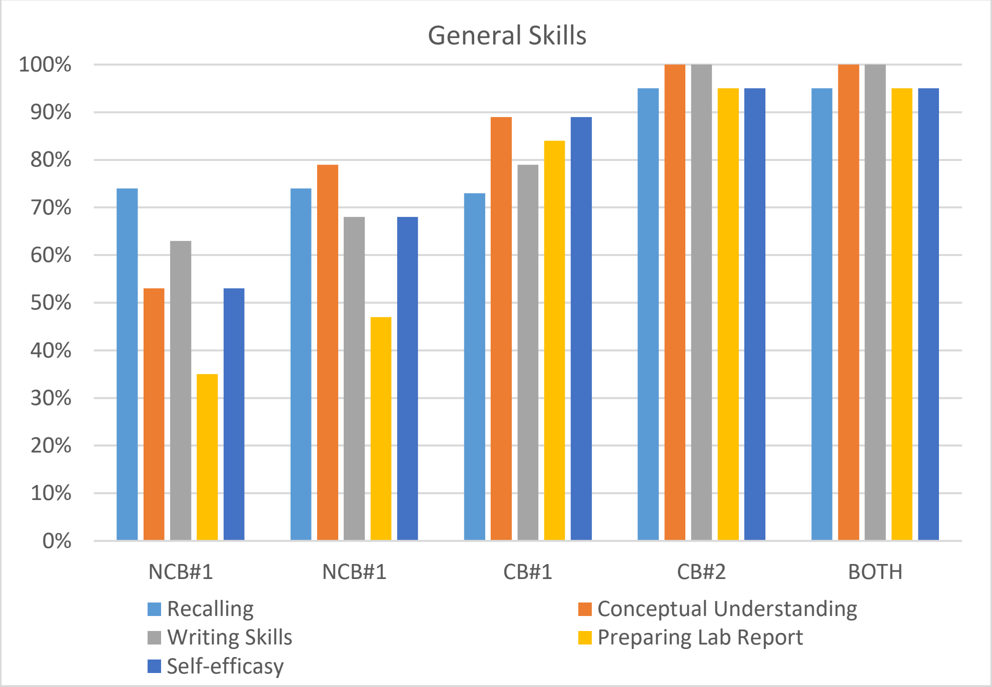

Figure 5. Survey Results of survey for improving general skills
Note: The percentage shows more than average choices; for instance: 90%, shows 90% of students at least chose average, above average or very high in their responses

This questionnaire included:

- Recalling: How much did the lab activity improve your ability to recall concepts?
- Conceptual understanding: How much did the lab activity improve your conceptual understanding?
- Writing Skills: How much did the lab activity improve your scientific writing skills?
- Preparing Lab Report: How much did you feel comfortable to write the lab report?
- Self-efficacy: How much did the lab activity improve your Self-efficacy?)

Investing ineffectiveness of NCB and CB lab activities

For Scientific skills in NCB types of activities, the "Ability to infer" was the toughest part for students, but the "Ability to predict", "Communicating and teamwork" as positive points were considerable. For other skills of NCB lab activities, the ability "Writing the lab report" was the toughest part for students. While the Ability "Recalling concepts" and "Conceptual understanding" as positive points were considerable (see **Table 2**). For Scientific skills in CB types of activities, "Ability to predict", "Being curious to experiment" and "Communicating, teamwork" were the toughest parts for students, but the "Measuring the quantities", "Sorting/classifying concepts" and "Communicating/teamwork" as positive points were considerable. For other skills of CB lab activities, the ability "Recalling concepts" was the toughest part for students. In addition, the abilities of "Conceptual understanding", "Self-efficacy" and "Scientific writing skills" are positive points. For Scientific skills of lab activity 5, the combination of NCB and CB, "Communicating and teamwork" was the toughest part for students. While the other parts of scientific skills as positive points were considerable.

Table 2. The Comparing positive and negative points for NCB, CB, Both lab activities

Type	Positive Points		Negative Points	
	Scientific Skills	General Skills	Scientific Skills	General Skills
NCB	-Predicting	-*Communicating* -Recalling concepts -*Conceptual understanding*	-Inferring	-Preparing lab reports
CB	-Measuring the quantity -Sorting concepts	-*Communicating* -*Conceptual understanding* - Self-efficacy -Writing skills	-Predicting	-Being Curious -*Communicating* -Recalling the concepts
Both	All	All	-	-*Communicating*

Conclusion

In this investigation, I compared two types of lab activities: CB and NCB. In CB, students were given a handout that describes the equipment they were to use and the steps they were to follow. NCB labs were taught by an instructor leaded students' learning by inquiry-based activities. I analyzed the students' answers for the questionnaire, and then compared the difference between the effects of lab activities on what students thought about their skills. Students, who took this course, can differentiate in their lab activities between CB and NCB.

- Students' active participation in the lab investigations will enhance their learning. Therefore, I plan this research to recognize students' choice depending on their thoughts for the best tools in an active learning.
- The type of doing experiments is important to improve students' learning in scientific method. Therefore, I create Cookbook (CB) Lab Activities and Non-Cookbook (NCB) Lab Activities in an active environment in Calculus based physics course.
- The comparison of using different types of lab activities can guide us to choose the most appropriate of them in teaching plans. Therefore, I investigate the benefits and challenges of these two types of lab activities in our physics course.

The results for scientific skills showed in NCB "Predicting" have improved; however, it was mentioned as the negative point of CB. In NCB, the "Ability to Infer" has negative point. In CB, "Measuring the quantity" and "Sorting/classifying" have positive points of improving scientific skills. For general skills, in NCB, "Recalling concepts" and "Conceptual understanding" were positive but "Inferring" and "Preparing lab reports" were negative. In CB, "Conceptual understanding" and "Scientific writing skills" and "Self-efficacy" were positive but "Predicting" and "Being curious to experiment" and "Recalling concepts" were the negative points. "Writing the lab report" is a tough skill in NCB, while it is easy for CB and "Conceptual understanding", is a positive point for NCB and CB. "Communicating", as a scientific skill is both negative and positive points in all types of activities. It seems it depends on the group of students rather than the type of activity. This is because students were supposed to change their groups for each session of lab activities. This study provides the intended learning benefits. Each type of lab activities has positive and negative points. Emphasizing the positive points and reducing the negative points could be a useful idea for planning for the future lab CB and NCB activities. Instructors and lab procedure planners can use these results to combine positive and reduce negative aspects of each type. In this research, the students' answers were investigated with students' evaluations of laboratory reports. The overall scores showed the result for this survey questionnaire is reliable.

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Disclosure Statement

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