Georgia Journal of Science

Volume 80 *No. 2 Scholarly Contributions from the Membership and Others*

Article 4

2022

STUDENT-DEVELOPED LABORATORY ACTIVITIES USING ROLLING OBJECT ON AN INCLINED PLANE TO IMPROVE STUDENT LEARNING

Qing Shao
Georgia Gwinnett College, qshao@ggc.edu

Joseph Ametepe
Georgia Gwinnett College, jametepe@ggc.edu

STUDENT-DEVELOPED LABORATORY ACTIVITIES USING ROLLING OBJECT ON AN INCLINED PLANE TO IMPROVE STUDENT LEARNING

Acknowledgements

The authors wish to thank the School of Science and Technology (SST) for providing funds, through the Course embedded research project mini-grant initiatives, to support this style of pedagogy. This fund is part of Georgia Gwinnett College's STEM grant initiative, which is supported by the University System of Georgia (USG) STEM Initiative phase II. This study received approval from Internal Review Board (IRB#:110068). Also, the authors want to thank Dr. Cynthia Woodbridge for the review and suggestions to the manuscript.

STUDENT-DEVELOPED LABORATORY ACTIVITIES USING ROLLING OBJECT ON AN INCLINED PLANE TO IMPROVE STUDENT LEARNING

Qing Shao
Joseph Ametepe
Georgia Gwinnett College
Lawrenceville, Georgia, 30043

ABSTRACT

This work presents an alternative method of teaching undergraduate introductory physics laboratory. Students are presented with an experimental scenario "Rolling object on an inclined plane" and guided to develop their own laboratory activities in a studio-style setting. The overall goal of this alternative approach is to shift part of the learning responsibility to students. Through guided self-developed activities, students establish the connections between different physics concepts. Such a shift makes students active participants in the classroom, allows them to explore ideas independently, and discover through doing the exploring. Furthermore, the pedagogy is aimed at (i) motivating and actively engaging students in the learning process, (ii) helping students learn how to think independently, (iii) developing scientific ideas, and (iv) taking ownership of the learning process. Assessment of data from a 3-year pilot study showed improvement in students' technical writing skills (30%), creative lab and research skills (6%), as well as critical thinking and quantitative skills (6%). In addition, students who participated in the study scored higher (6%) than their control group counterparts on the final exam. Other benefits are improvement in understanding of the research process and laboratory technical skills.

Keywords: introductory physics lab, inclined plane, rolling object, self-developed, creativity, laboratory skills, data analysis & technical writing skills.

INTRODUCTION

The study presented here was conducted for 3 years in a set of introductory physics courses in Georgia Gwinnett College. The college is an open-access and devoted to student success, committed to an integrated educational experience, encourages new teaching pedagogy, and the innovative use of educational technology. The college currently enrolls close to 12,000 students and is labeled as the college with the most diverse student population (33% Black/African American, 17% Hispanic, 35% White, 10% Asian, and 5% other) in the state public institution system. There are several Course-Embedded undergraduate research experiences (CURE) for students majoring in science, including students in algebra-based physics. Most of the students who are taking algebra-based physics are Exercise Science and Biology majors. A typical class comprises lectures, problem-solving, and laboratory sections within the allotted time. During the problem-solving section, students break out into small groups to work on a set of problems developed specifically to address concepts covered in the lectures. The problem-solving section is then followed by specific laboratory activity (or mini-project) designed to further elucidate concepts covered in the lecture period. The algebra-based physics course traditionally covers classical mechanics (in the first semester) and optics, electricity, and magnetism (in the second semester).

In a recent internal survey on Retention, Progression and Graduation in STEM ("School of Science & Technology RPG+S Data" 2019), 80% of responding students taking introductory physics courses stated that physics is different from the other science courses. Students indicated that the physics concepts are tedious, too abstract, and fundamentally irrelevant to their future careers. Such perceptions have been noted to be common among students majoring in other STEM-related fields (Laws 1997; Redish 1994; Redish et al. 1997, 1998). Internal course assessment data of introductory physics suggests that students are successful in temporally grasping the fundamental concepts to perform reasonably well on exams.

However, an independent follow-up on the performance of students who completed physics (algebra & calculus-based), shows that a greater percentage are unable to recollect or apply physics-related concepts. Also, some of these students (algebra & calculus-based) are (i) unable to independently develop research ideas, and (ii) effectively analyze scientific data collected from laboratory experiments. The authors of this work believe that the cookbook traditional physics laboratory approach tends to be ineffective in helping students develop critical, research, and technical writing skills. To address deficiencies in the cookbook traditional approach, other groups have used interactive teaching methods to better engage students and proposed the need for using purposeful and interactive activities in the classroom (Beichner et al. 2007; Bransford et al. 2000; Livingstone et al. 2002). The American Association of Physics Teachers (AAPT) also released recommended goals for undergraduate physics laboratory curriculum addressing Designing Experiments, Constructing Knowledge, Analyzing Data, Developing Technical and Practical Skills and Communicating Physics ("Report: AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum" 2015). More recently, other groups have used the Student-Centered Active Learning Environment for Undergraduate Programs (SCALE-UP), inquiry-based, and investigative style labs to actively engage students in the learning process (Beichner 2008; Dale et al. 2019; Foote et al. 2018).

This work, funded by the USG STEM initiative II, presents an alternative method of teaching undergraduate introductory physics laboratory. Students are presented with an experimental scenario and guided to develop their own laboratory activities in a studio-style setting. The method, approved by an institutional review board (IRB#:110068), was designed and implemented for three years in an integrated lecture and laboratory classroom setting (studio-style). About 100 students participated in this study in total. In this format, lectures and laboratory activities are combined in 2 hours and 45 minutes sections, with class sizes limited to a maximum of 24 students. Furthermore, the method takes advantage of results of physics education research and cognitive science guidance to include features of the cognitive apprenticeship model, iterative cycle of coaching, scaffolding, and reflection (Collins 1988; Collins et al. 1988; Hake 1998; "Vision and change: A call to action, final report" 2011). Students working in small teams are challenged to design a laboratory activity, formulate protocols for collecting data, design a method of analyzing data, and draw conclusions based on their work as opposed to the traditional cookbook approach. The format of this work is different from other inquiry problem-based approaches. The activities are not isolated, but rather a semester-long series of interconnected concepts. Such interconnected concepts (through activities) allow students to better understand the connection between different concepts in mechanics. However, this method is similar to others because of its inquiry-based nature. The study had experimental and control groups (E- and C-groups).

DESIGN AND IMPLEMENTATION

The activity design revolves around a scenario (TABLE 1) that is divided into smaller weekly activities. Each activity addresses a specific topic(s) to be completed during regular class (laboratory) time. Students are expected to submit their completed work to the instructor no later than one week after the activity is completed. The instructor supervised all the activities and graded all the reports without the use of teaching assistants.

TABLE I. Scenario, Statement of Problem, and Concepts to be addressed

Scenario	Statement of Problem	Concepts addressed
A cart or a rolling object is to be released from the top of an inclined plane (see fig. 1) such that it will accelerate down the inclined plane until it reaches the bottom of the inclined plane, after which it continues to roll along the floor.	Develop and conduct experiments to collect data to calculate the object's linear and angular velocity, linear and angular acceleration, as well as forces and torques acting on the object **Note:** This activity will be divided into a series of sequentially dependent inquiry-based labs and will be completed over one semester.	**01:** object's acceleration as it moves down the inclined plane and final velocity of the object at the bottom of the inclined plane. **02:** Forces acting on the object as it moves down the inclined plane and then on the floor. **03:** angular speed, angular acceleration, and torque of the object as it rolls down the inclined plane and continues rolling on the floor **04:** conservation of energy to determine the linear and angular speed of the object at the bottom of the inclined plane

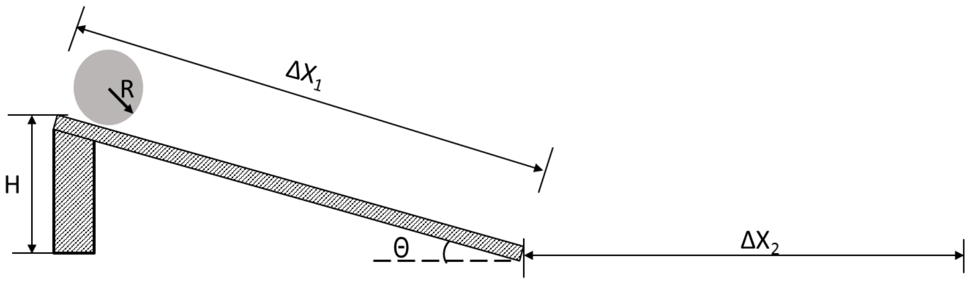

FIGURE 1. Schematics of the Scenario - Rolling object on the inclined plane. ΔX1: Displacement on the ramp, ΔX2: Displacement on the floor, Θ: Angle of the ramp, H: Height of the ramp, R: Radius of the rolling object

The activities are strategically designed to complement specific lecture topics, as such the activities are executed only during certain weeks while other weeks are used to conduct traditional cookbook laboratory activities, for example measuring range and height for projectile motion, speed before and after elastic and inelastic collisions. In all, students complete four lab reports (one regular report and three formal reports Flab 02 – Flab 04). The first regular lab report is based on a series of short-answer questions to prompt students to think about the basic project design. A point worth noting is that students only use lab times of weeks 3, 7, 10, & 13 to perform their developed activities related to their self-developed projects.

The weekly procedures followed are (1) grouping of students, explaining lab format and grading procedure, (2) introducing concepts of data collection and analysis, (3) designing experimental procedures and establishing formal steps for the lab reports by student teams, (4) setting up experiments, collecting and analyzing data, (5) writing Flab 02 reports by student teams and providing feedback on Flab 02 reports by the instructor, (6) analyzing data on rotational motion and writing Flab 03 reports, addressing instructor feedback and updating Flab 02 reports by students teams, (7) providing feedback on Flab 03 reports by the instructor, (8) analyzing data on conservation of energy and writing Flab 04 reports, addressing instructor feedback and updating Flab 03 reports by student teams, and (9) providing feedback on Flab 04 reports by the instructor and suggestions for follow-up work. The weekly detailed activities are summarized below.

In week one, the instructor divides the class into teams consisting of three to four students. To promote team diversity and limit the possibility of undue advantage of one team over the other, the instructor carefully selects students for the teams. The instructor also explains the format of the lab and grading rubrics, and covers the concepts of experimental errors, propagation of errors and uncertainty.

In week two, the basics of excel (graphing, curve fitting, error bars, interpretation of slope, intercepts, and the relationship between independent and dependent variables*)* and data analysis are covered through remedial activities. These remedial activities are pre-designed to target specific skills that the authors anticipate students would need throughout the semester.

In week three, students examine the various forms of rolling objects (Fig. 1) and measuring devices available to them (stopwatches, angle locators, protractors, tape measures or meter sticks, etc.). Each team is challenged to explore design set-ups, develop a complete experimental procedure that will allow them to effectively collect, analyze data, and calculate variables related to 1-D kinematics. Key components of the protocol are for students to include (i) a justification for the experimental method, (ii) the selection of materials needed, (iii) what specific parameters will be measured, (iv) how data will be collected, (v) how the data will be analyzed including any graphs that will be plotted, and (vi) which equations will be used. Each team takes turns to present their set-up and data collection protocol to the class. The instructor, together with the rest of the class, asks questions and provides additional feedback to the presenting team for improvement. The teams are then required to use the feedback to edit and submit an updated version of their experimental procedure for instructor approval. Weeks four through six are used to cover vectors, concepts of Newton's law of motions, free-body diagram (FBD), friction, and forces. Traditional cookbook lab activities are completed by students during these weeks, such as measuring and calculating displacement vectors on the map, measuring and correlating force and acceleration for Newton's Second Law.

In week seven, students are challenged to construct the scenario (Fig. 1) and use their instructor-approved procedure from week three to test their protocol. Student teams are required to document practical challenges they encounter (if any) regarding the suitability of rolling object, optimal angle (θ), height (H) of the inclined plane, the inclined distance (ΔX_1) along the inclined plane, and the range (ΔX_2) the rolling object travels along the floor. Each team can decide how far they want to measure the distance (ΔX_2) for their specific work. Students then implement their improved design protocols to collect data of ΔX_1, ΔX_2 and time (t) needed to calculate velocity(v), and acceleration(a). Students' objectives are to determine (i) the forces acting on the object as it moves down the inclined plane and (ii) the forces acting on the object as it moves on the floor. In both cases, students are required to draw the free-body diagram (FBD) to establish a method to calculate the magnitude and direction of the forces. By the end of week seven, students should have completed all necessary activities to allow them to write a formal laboratory report (FLab 02) to include sections of Introduction, Procedure, Data, Analysis, Results, Discussion and Conclusion. During weeks eight and nine, concepts of Rotational kinematics and dynamics, angular speed, angular acceleration, torque and the moment of inertia of various shapes are covered.

In week ten, students are challenged to use data and information gathered from week seven to determine the angular speed(ω), angular acceleration(α), and torque (τ) of the object as it rolls down the inclined plane and along the floor. Students focus on refining their data analysis techniques to allow them to calculate ω, α, and τ from results of linear speed (v), linear acceleration (a) and forces (F). Additional requirements in week ten are (i) FBD of the rolling object (modeled as a shape, not a point) with forces rightly indicated, (ii) Use two methods to determine the moment of inertia (I) for the rolling object: calculate (I) based on the shape of their object and from Newton's second law for rotational motion ($\tau = I\alpha$). Students are required to complete a formal lab report (FLab 03) similar to FLab 02 for this activity. During weeks eleven and twelve, concepts of conservation of energy, potential energy, linear kinetic energy, rotational kinetic energy and work done by friction are covered.

In week thirteen, students are challenged (using measurements of angle, distance and etc. from week seven) to determine v and ω from concepts of conservation of energy. Results obtained from week thirteen are to be compared to results obtained from week seven and ten. Additional requirements for week thirteen are (i) discuss possible reasons for differences in results obtained through different approaches, and (ii) discuss the role that friction force play in the analysis of conservation of energy. Students are required to complete a formal lab report (FLab 04).

ASSESSMENT

A combination of methods (FLabs reports and final exam grades) were used to assess the four goals of 1. understanding of concepts, 2. creativity and research skills, 3. critical thinking, and 4. technical writing skills. Also, analysis of student responses to pre-and post-questionnaire offered insight into students' perspectives about the activities.

Each team's formal lab reports were graded using rubrics similar to published methods (Black et al. 1996). To help streamline the evaluation process, related standards were grouped into four goals (Table II in Appendix) consistent with recommendations by the American Association of Physics Teachers ("Report: AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum" 2015). The rubrics included ten standards (labeled S1 through S10 shown in table II), each at four scale levels as shown in table III.

The end of semester final exam (administered to both the E- and C-groups) results were used to evaluate students' ability to apply physics concepts to answering questions. The cumulative final exam with the same difficulty level is administrated to students over the three years of the study.

Pre- and post-survey questionnaire (Q1 – Q10), conducted via Desire2Learn platform to be completed by students within a given time frame without the presence of the instructor. The results were analyzed to assess students' perception of their mastering of the four goals. Each survey question was evaluated using a 5 Likert scale: strongly disagree (1), disagree (2), neutral (3), agree (4) and strongly agree (5), balanced on both sides of a neutral choice to create a less bias measurement (Elby et al. 2001). For analysis purposes, the survey questionnaire (Q1 – Q10) was grouped as shown in Appendix (Table IV).

RESULTS

Average scores for rubric standards addressing the four areas identified above for the E-group covering FLab 02, FLab 03, and FLab 04 are shown in Figure 2 below:

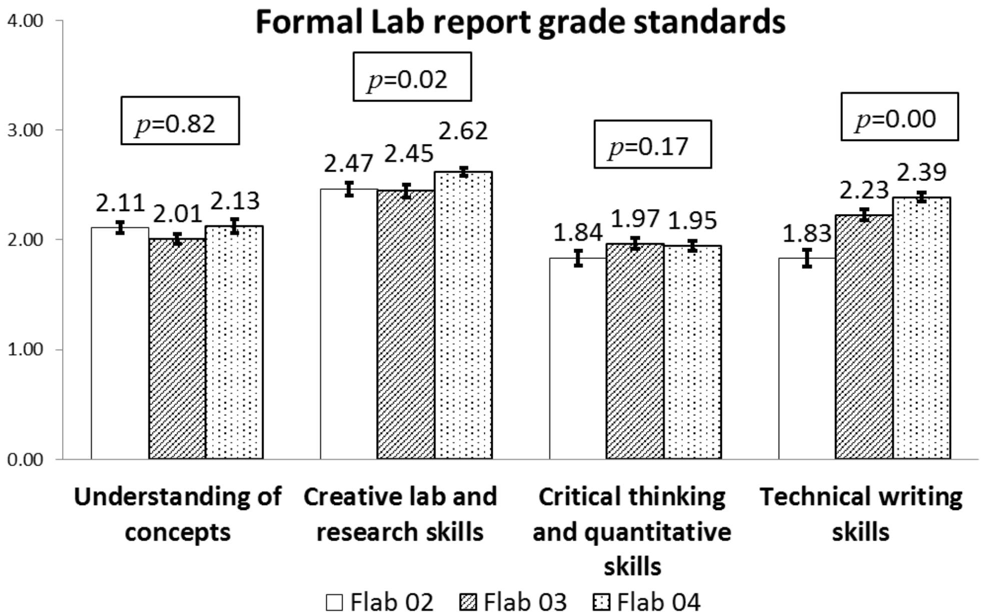

FIGURE 2. Average scores for rubric standards for the E-group over the three major activities. The error bar represents the standard error of the mean (SEM). A p-value of the paired two-tailed t-test comparing FLab02 and FLab04 is shown above the bars.

The average end-of-semester final exam grades for both the E- group (sample size 95) and C-groups (sample size 84) are shown in figure 3; the E-group performed better (E-group about 5% points > C-group on final exams), with a p-value of 0.03.

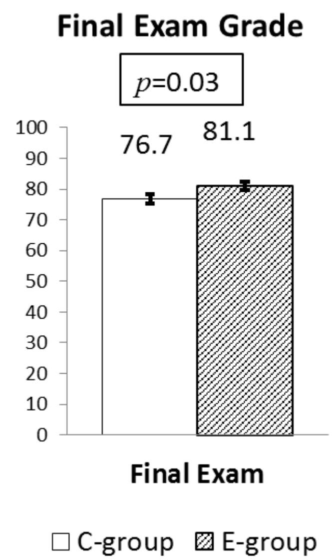

FIGURE 3. The average final exam grade is based on 100 points for the E- and C-group. The error bar represents the standard error of the mean (SEM). A p-value of the unpaired two-tailed t-test comparing E-group and C-group is shown above the bars.

The average scores of pre-and post-surveys are shown in figure 4 for E-group and C-group.

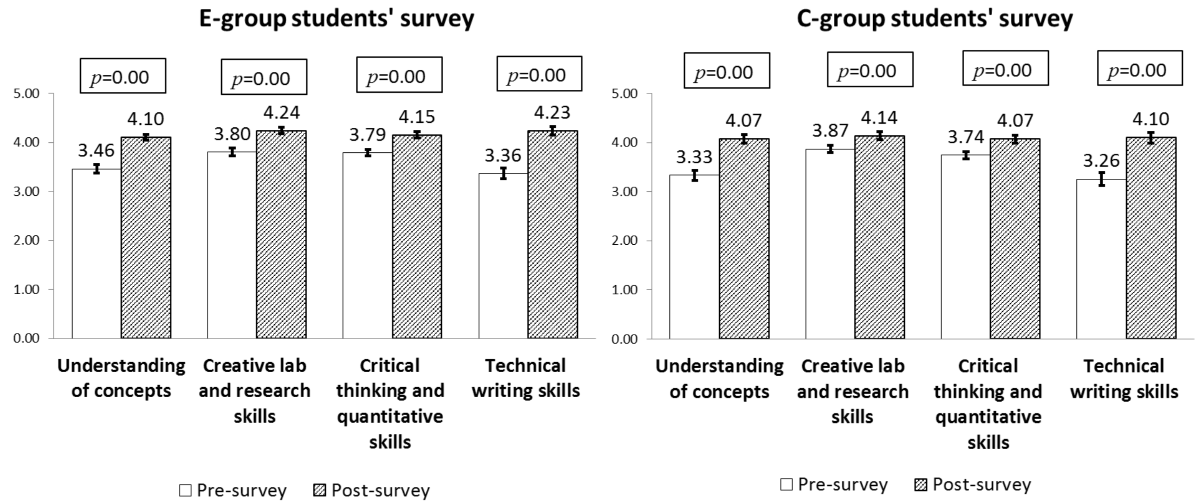

FIGURE 4. Average pre-and post-survey scores for E-group and C-group. The error bar represents the standard error of the mean (SEM). A p-value of the paired two-tailed t-test comparing students' scores between pre-and post-surveys in these four areas are shown above the bars.

The differences between pre-and post-survey were calculated for individual students and then averaged for E-groups (sample size 69) and C- (sample size 58) addressing the above four areas are shown in Figure 5.

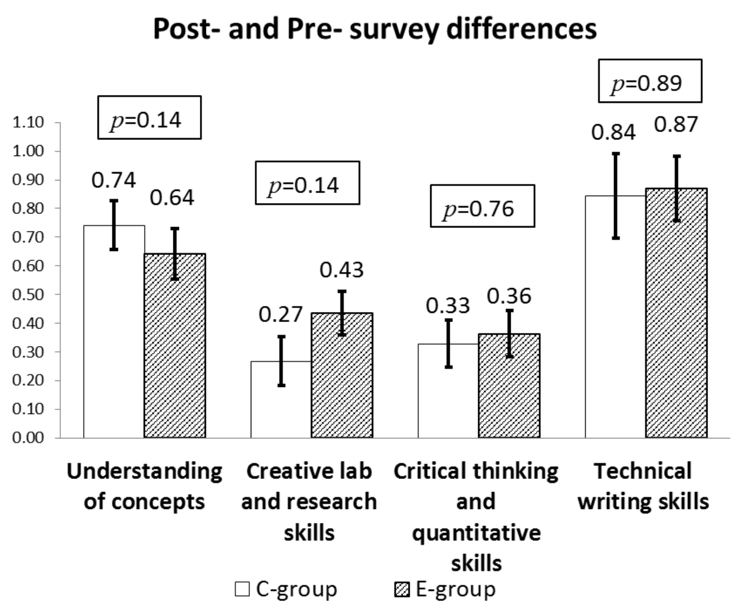

FIGURE 5. Differences are calculated using post- survey score minus pre-survey score for the individual student and then averaged. The error bar represents the standard error of the mean (SEM). A p-value of the unpaired two-tailed t-test comparing E-group and C-group in these four areas are shown above the bars.

DISCUSSIONS

The rolling object on an inclined plane is a traditional problem in introductory physics. There are several reasons the authors chose this "simple" problem as the scenario for this project. First, the materials are readily available, setup is simple, and sufficient references are readily available from textbooks and class notes. Second, students learn that regardless of how "simple" an activity may seem, there are many details involved when applying textbook concepts to real-world situations.

All students (E- and C-group) enrolled in the introductory physics (algebra-based) course had obtained a grade of C or better in their pre-requisite courses, and so no one group had an advantage of background preparation over the other. The instructional part of the courses was the same for both groups. Students did not self-select to which study group (E- or C-group) to belong; the specifications of the E- and C-groups were announced after the classes started. The E- and C- group has similar percentages of students from Exercise Science and Biology majors and both majors get comparable research experiences.

Because some students who took the final exam did not participate in both pre-and post-survey, the sample sizes for the survey are smaller than that of final exam grades for both E- and C-group. E- and C-groups are from different sections of the course, some sections have lower enrollments which results in the different sample sizes between the E- and C-group.

All p-values are rounded to 2 decimal places. $p=0.00$ in the graphs means the actual p-value is smaller than 0.005. When p-values are less than 0.05, the differences of the data from the E- and C-group are statistically significant, however, low p-values even if over 0.05 also indicate the results are numerically different.

The survey results only provide the students' perception of the project, which is not the basis for our conclusion. First, the questionnaire used for the survey (Table IV) may not capture the entirety of the study we planned to conduct, second students' perception is not always aligned with the actual improvement of their skills, for example, the E-group scored less in understanding of the concepts, but they did better in the final exam. We believed the final exam score and lab report grade are more objective and reliable to conclude from.

Formal lab reports assessment (Figure 2)

Understanding of concepts scores averaged between 2.01 to 2.13 with a p-value of $0.82 > 0.05$. The lack of obvious improvement in scores from FLab 02 to FLab 03, maybe due to the difficult nature of the rotational kinematics unit related to FLab 03. The authors speculate that the slight increase in average scores from FLab 03 to FLab 04 may be due to students getting accustomed to the challenges of the new methodology and thus being able to appropriately apply the right concepts to solving problems. Creative lab and research skill scores increased from 2.47 to 2.62 (about 6% improvement from FLab 02 to FLab 04), with a p-value of $0.02 < 0.05$ (Figure 2). The authors observed that students are able to consistently apply skills gained from previous activities to later activities. Critical thinking scores only improved from 1.84 to about 1.95 (about 6% improvement from FLab 02 to FLab 04), with a p-value of 0.17. The average score was 1.92 and represented the lowest average score for the four areas evaluated. Again, these numbers are not surprising as the development of critical and quantitative skills takes time to build.

The technical writing skills data in Figure 2 indicated progress from one formal lab report to the next. Compared with the other skills evaluated, student's technical writing skills improved the most from an average of 1.83 scores in FLab 02 to an average of 2.39 score for FLab 04 (about a 30% improvement). The improvement can be attributed to the iterative review and re-writing process.

Final Exam (Figure 3)
The same final exam was administered to both the E- and C-groups and the same grading rubrics were applied. The E-group scored an average of 5% higher (Figure 3) than their counterparts in the C-group. We speculate that this difference is because the E-group students spent more time in their self-developed activities to (i) explore how concepts are related, (ii) test how concepts are directed to the activity they were performing, (iii) interact to exchange ideas, and (iv) consistently working with instructors to seek understanding. These factors may have contributed to the deepening of students' understanding leading to retaining of major concepts.

Survey questionnaire (Figure 4 and 5)
Figures 4 and 5 show the pre-and post-survey scores. The score for the E-group was higher than the C-group in the critical lab and research skills, critical thinking and analytical skills. The results are not surprising as the E-group (i) had many more chances to repeat skills through self-developed activities, (ii) were required to explore methods that worked best for their specific activities and discuss the uncertainty for data analysis, and (iii) experienced the report writing and review process as one of the key aspects of the activities. However, for the understanding of the concept, the score increase for the E-group was lower than that of the C-group. This may be because students in the E-group realized that their understanding of concepts was not as strong as they thought; the self-developed activities exposed that gap.

While there were significant gains in this new approach, there were still fundamental problems with students being able to carry out simple calculations correctly. This problem, in the authors' opinion, is not particularly an inherent problem with the adopted method but rather the lack of mathematical background preparation in algebraic and pre-calculus concepts.

Also, Fig. 5 presents the results of students' perception of their gains in technical writing. The figure shows no statistical difference between the E- and C-groups. This perception result is slightly misleading as developing technical writing skills takes time. The clear, direct, and neutral style of technical writing requires regular practice and an extended learning period to establish confidence. In this work, the E-group students spent more time completing their formal laboratory reports than the C-group.

Instructors, grading students' work, saw writing improvements from one lab report to the other for the E-group. The perception results, of no statistical difference between the E- and C-group, on the gains in technical writing skills, maybe due to several factors including (i) the writing period (a semester) was not long enough for students to establish a level of confidence in technical writing skills, (ii) the questionnaire used for the survey (Table IV) may not adequately capture the entirety of what is needed to evaluate technical writing skills, and (iii) students associating longer report writing times to lacking skills.

Student outcomes

The study presented here had several outcomes. The study positively influenced students' attitudes toward learning. Also, students (i) took ownership of the learning process through the repeated hands-on nature of the student-driven activities, (ii) gained concept knowledge, developed skills/creativity in conducting simple experiments, and (iii) improved peer collaboration through the free exchange of ideas with peers. Additionally, students worked with intrinsic motivation in a welcoming classroom environment. The above outcomes translated into improved student achievement as evidenced in the final grade distributions. These findings are consistent with other student outcomes related to inquiry instructions (Saunders-Stewart et al. 2012)

CONCLUSIONS

The laboratory method presented in this work is a low-cost, easy-to-implement, and high-impact practice that shifts part of the learning responsibility to the student. The method encourages partnership among students, empowers and provides them with a collaborative learning environment. Additionally, the method fosters students' ability to think, develop scientific ideas independently, and teaches them to take ownership of the learning process. Students in the E-group showed marked improvement in the application of physics concepts to solving problems, evident in final exam grades. The laboratory reports and pre-and post-questionnaire analysis showed that the approach was effective in helping students develop research and technical writing skills, improve their creative, critical, and quantitative reasoning skills. Additionally, the authors observed overall positive attitudinal changes, students took ownership of their work and were more willing to share/defend their methodology or way of carrying out a specific activity. Furthermore, students interacted more with the instructor to seek feedback on their work. Students were compliant and driven to get good results for their invested time. We believe that students from the C-group would have achieved a comparable level of gains if they participated in the self-developed activities. The presented method had several student outcomes that included understanding of the scientific process, improved motivation and collaboration, taking ownership of the learning process, building skills conducting simple experiments, and willingness to repeat experiments to verify results.
Finally, this new method provided several advantages to student learning (improved student grades, report writing skills, lab and research skills as well as critical thinking and quantitative skills).

ACKNOWLEDGMENT

The authors wish to thank the School of Science and Technology (SST) for providing funds, through the Course embedded research project mini-grant initiatives, to support this style of pedagogy. This fund is part of Georgia Gwinnett College's STEM grant initiative, which is supported by the University System of Georgia (USG) STEM Initiative phase II. This study received approval from Internal Review Board (IRB#:110068). Also, the authors want to thank Dr. Cynthia Woodbridge for the review and suggestions to the manuscript.

REFERENCES

Beichner, R. J. 2008. The SCALE-UP Project: a student-centered active learning environment for undergraduate programs. An invited white paper for the National Academy of Sciences.

Beichner, R. J., J. M. Saul, D. S. Abbott, J. J. Morse, D. Deardorff, R. J. Allain, S. W. Bonham, et al. 2007. The student-centered activities for large enrollment undergraduate programs (SCALE-UP) project. Research-based reform of university physics, 1(1), 2-39.

Black, B., M. Gach, and N. Kotzian. 1996. Guidebook for teaching labs for University of Michigan Graduate Student Instructors. Center for Research on Learning and Teaching, University of Michigan.

Bransford, J. D., A. L. Brown, and R. R. Cocking. 2000. How people learn. National academy press.

Collins, A. 1988. Cognitive Apprenticeship and Instructional Technology. Technical Report. Cambridge, MA: BBN Laboratories Incorporated.

Collins, A., J. S. Brown, and S. E. Newman. 1988. Cognitive apprenticeship: Teaching the craft of reading, writing and mathematics. Thinking: The Journal of Philosophy for Children, 8(1), 2-10.

Dale, D. A., J. Sutter, and D. Kloster. 2019. Asking Real-World Questions with Inquiry-Based Labs. The Physics Teacher, 57(8), 547-550.

Elby, A., J. Fredrikson, C. Schwarz, and B. White. 2001. Epistemological Beliefs Assessment for Physical Science. http://www2.physics.umd.edu/~elby/EBAPS/home.htm

Foote, K. and S. Martino. 2018. Implementing investigative labs and writing intensive reports in large university physics courses. The Physics Teacher, 56(7), 466-469.

Hake, R. R. 1998. Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. American Journal of Physics, 66(1), 64-74.

Laws, P. W. 1997. Millikan Lecture 1996: Promoting active learning based on physics education research in introductory physics courses. American Journal of Physics, 65(1), 14-21.

Livingstone, D. and K. Lynch. 2002. Group project work and student-centred active learning: Two different experiences. Journal of Geography in Higher Education, 26(2), 217-237.

Redish, E. F. 1994. Implications of cognitive studies for teaching physics. American Journal of Physics, 62(9), 796-803.

Redish, E. F., J. M. Saul, and R. N. Steinberg. 1997. On the effectiveness of active-engagement microcomputer-based laboratories. American Journal of Physics, 65(1), 45-54.

Redish, E. F., J. M. Saul, and R. N. Steinberg. 1998. Student expectations in introductory physics. American Journal of Physics, 66(3), 212-224.

Report: AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum. 2015. The Physics Teacher, 53(4), 253-253. doi:10.1119/1.4914580

Saunders-Stewart, K. S., P. D. Gyles, and B. M. Shore. 2012. Student outcomes in inquiry instruction: A literature-derived inventory. Journal of advanced academics, 23(1), 5-31.

School of Science & Technology RPG+S Data. 2019. Georgia Gwinnett College.
Vision and change: A call to action, final report. 2011. American Association for the Advancement of Science.

APPENDIX

TABLE II. Lab rubric standards (S1 – S10)

	Standard	Goals
S1	Understanding of research question, ability to apply appropriate equations to perform calculations, used correct units and significant figures	Understanding of concepts
S2	Ability to use correct physics terms in writing reports	
S3	Appropriate design of data collection procedure	Creative lab and research skills
S4	Instrument use and data collection was adequate	
S5	Completeness of assigned activity	
S6	Students used instructor's feedback	
S7	Student's ability to solve problem using the correct mathematical formulation	Critical thinking and quantitative skills
S8	Student's ability to discuss error/uncertainty in their results and propose improvements	
S9	Student's ability to present lab report in the right format	Technical writing skills
S10	Student's ability to present data in the appropriate scientific format	

TABLE III. A scale that differentiates between demonstrated levels of performance.

Level of scale	Criteria for report grade	Score (grade)
Does not meet the expectations	Incomplete, misapplied concepts, or incoherent ideas (less than desired)	1 (< 70%)
Approaching expectations	Shows an application of developing skills with room for improvement	2 (70% – 80%)
Meets expectations	Report meets expectation	3 (81% - 90%)
Exceeds expectations	Clearly represents a superb performance	4 (91% - 100%)

TABLE IV. Pre- and post-survey questions (Q1 – Q10)

	Pre- and post-survey questions	Goals
Q1	Understood the physics concepts before starting the related lab activity.	Understanding of concepts
Q2	Use proper physics formula to analyze experimental data.	
Q3	Understood how force, velocity and energy are related to each other	
Q4	Design and carry out experiment to find the speed of an object.	Creative lab and research skills
Q5	Use the meter stick and stopwatch or photogate to properly measure length and time respectively.	
Q6	Confident I can troubleshoot my lab if problems arise.	
Q7	Usually read and learn from feedbacks of my lab report provided by instructor.	
Q8	Always think of alternative experimental approach to acquire the final results in the lab.	Critical thinking and quantitative skills
Q9	Understand there is always uncertainty associated with the measurements in the lab	
Q10	Can write a lab report using appropriate physics terminology	Technical writing skills