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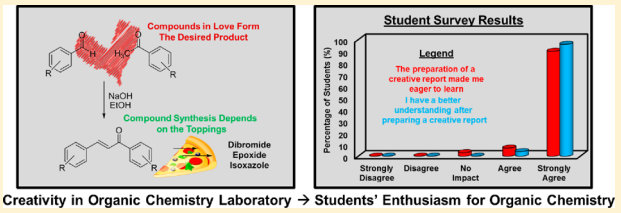
Creative Report Writing in Undergraduate Organic Chemistry Laboratory Inspires Nonmajors

Maged Henary,*[,†,‡,§] Eric A. Owens,[†,‡,§] and Joseph G. Tawney[†]

[†]Department of Chemistry, [‡]Center for Diagnostics and Therapeutics and Center for Biotechnology and Drug Design, Georgia State University, Atlanta, Georgia 30303, United States

ABSTRACT: Laboratory-based courses require students to compose reports based on the performed experiments to assess their overall understanding of the presented material; unfortunately, the sterile and formulated nature of the laboratory report disinterests most students. As a result, the outcome is a lower-quality product that does not reveal full understanding of the material. We have found that by allowing students to be more creative while preparing the introduction of their research reports, a greater enthusiasm for the organic chemistry course is stimulated because students are able to relate to the seemingly irrelevant reactants and mechanisms; this is often reflected in their laboratory reports, which are highly creative while maintaining crucial scientific integrity in the remainder of the report discussing experimental protocol, mechanisms, and all corresponding data.



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INTRODUCTION

Future scientists must learn how to effectively communicate difficult scientific principles to an audience sometimes unfamiliar with the particular subject. This is no different in the organic chemistry II laboratory, where report preparation has always been the accepted method for students to convey their understanding of techniques and concepts.[1−5] Various methods for modifying the common writing process that have been reported[6] include structuring laboratory report preparation around an article for submission to the *Journal of the American Chemical Society* or a "real-world" research style lab report.[7,8] We feel that a more creative approach is often beneficial for beginning organic chemistry students. Recently, a geology professor reported having his students write letters to a fictitious uncle who was financing their education detailing their scientific observations.[9] The professor observed higher quality writing, more in-depth analyses and overall better quality work when students were allowed to be creative; we have experienced a similar effect in our teaching at Georgia State University (GSU).

Every semester at GSU, the chemistry department offers the organic chemistry II laboratory course, which accommodates the many enrolling undergraduate students. Among these students are a few dedicated to studying chemistry, whereas others show less enthusiasm toward learning the intricate techniques and are more interested in pursuing a career path that does not necessarily require organic chemistry knowledge. For instance, some students taking this course are business majors, and others plan to study photography or biology. Furthermore, a substantial number of students plan to move on to medical school instead of pursuing a career in organic chemistry. A notable goal of this particular organic chemistry lab course at GSU is to offer incoming students a new perspective toward chemistry through a unique and established learning environment. Students often complain about the requirement of constructing a formal, rigid, and often-lengthy report that involves documenting cited literature, experimental methods, and scientific conclusions of their semester's work. Unfortunately, the sterile nature of general undergraduate chemistry courses discourages many students from enjoying the astonishing science behind the reactions they accomplish throughout the semester. Many students learn organic chemistry through their own imaginative process. To accommodate these students, some of the organic II laboratory sections offer the option of preparing a lab report that includes a creative introduction where students may write a story drawing parallels to their chemical reactions, instead of complying with the more formal, rigid guidelines most introductions follow. The remainder of the lab report must adhere to traditional standards and be presented in a formal, scientific manner. It has been observed that students become more passionate and "in-tune" with their following lab report as they begin seeing the chemistry happen in their own vernacular rather than memorizing the structures and terminology presented to them. This idea of utilizing a student's creativity to invoke their understanding and passion toward a particular subject has been investigated previously and has shown great success.[6] We now report the use of an educational method that allows for the creative stimulation of chemistry students, especially nonmajors, in organic chemistry II laboratory that promotes the appreciation and understanding of the presented material.

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GENERAL LABORATORY OVERVIEW

Students taking the organic II lab class at GSU are assigned individual projects that consist of the synthesis of a unique chalcone. More independent students are given syntheses that are not found in the open literature; we have also found that performing the synthesis of unknown compounds excites students (not elaborated on herein). After chalcone synthesis, students must prepare additional compounds based on the reactivity of the α,β-unsaturated ketone functionality, including bromination and epoxidation, with the target being the corresponding diarylisoxazole. After completing their synthesis and structure and purity proof, students are required to conduct an extensive literature search using well-known databases (Reaxys and SciFinder) to identify the novelty of their particular compounds. After all wet-lab experimentation has been completed, the students are required to submit a final report documenting their findings.

Each laboratory class is comprised of approximately 40 students, three teaching assistants, and the professor who is present throughout the duration of the class. Every semester there are four organic II laboratory classes taught by a variety of professors. Each class is generally made up of the same number and type of students. Some are chemistry majors, though a majority of them plan to pursue other fields of study, ranging anywhere from biology to music. Before each lab, the class meets with the professor for about an hour to be given an explanation of the experiment that day. This lecture includes safety procedures, a discussion regarding reaction mechanisms, and any other pertinent information the student needs to know in order to be successful. During some of these lectures, a quiz is given that tests the students' knowledge over material presented in the past. All students across classroom sections are given identical assessments. In addition to these quizzes, students must log their laboratory experiment into their notebooks. These notebooks are graded periodically, and at the end of the semester, every organic II laboratory student takes the same standardized final exam that contains both multiple choice and open-ended critical thinking questions within the sections of structure nomenclature, reaction mechanisms, logical laboratory questions, calculations, and NMR (proton and carbon) determination. The only difference from class to class is whether or not the professor gives the option of writing a creative report at the end of the semester.

THE FINAL REPORT

Encouragement to write high quality and thoughtful laboratory reports is crucial, but many students generally regard this as "dull" or "tedious" due to complying with rigid, standardized guidelines that generally remove any personality and creativity in the writing process. At GSU, encouraging students to be creative serves as a gentle introduction into writing laboratory reports and helps alleviate the start to the unfamiliar task of scientific writing. When they are given the opportunity to mold their own unformulated introductions into an imaginative story, students demonstrate a higher degree of understanding and are able to communicate the difficult subject in their own unique way. For example, past students have incorporated the synthesis of benzalpinacolone or chalcone into a metaphor of cooking a pizza[10] or a relationship and have successfully incorporated the chemical details into a story relating to daily life. The students seem to enjoy writing these introductions, as the stories get very creative; however, a balance between allowing academic freedom and correct education for writing lab reports is maintained by requiring students to correctly annotate and describe their compounds. For example, they have to report what was observed during synthesis and describe physical data like melting point and nuclear magnetic resonance spectroscopy (^{1}H and ^{13}C NMR data). Thus, all information is reported in detail, drawings of chemical equations are done electronically, sources are cited appropriately, NMR spectra are scientifically annotated, and appropriate arrow pushing mechanisms are drawn for each synthesis. Below is a sample of a student's creative work. The students gave us permission to use excerpts from their introductions to showcase creative writing.

> *"If there is ever a time you can't decide what to eat, pizza will always be a great choice. It has been my dream to open up a pizza joint. Finally, this dream has come true, but I wanted the pizza place to be special. So I decided to synthesize chalcone pizza. My most basic pizza will have two toppings, benzaldehyde and acetophenone, which takes part in a base-promoted Aldol condensation to produce a yellow chalcone pizza. The second pizza will be called a chalcone dibromide pizza and it will be made by sprinkling on Br^+ and Br^- ions on to the chalcone pizza's double bonds. The hardest pizza is the isoxazole pizza, which required cooking the chalcone dibromide pizza with a special topping, $NH_2OH{-}HCl$. The next pizza will be an epoxide pizza, which was created from the chalcone pizza by Michael addition to the α,β unsaturated double bonds using H_2O_2 and a base. Each pizza was tested for perfection through methods such as IR, UV, NMR, and melting point. My goal was to make the best pizza with simple ingredients."*[10]

Shown by the creativity in the laboratory excerpt, the student demonstrated a thorough understanding of the lab concepts and reactions learned throughout the course. In this particular case, the student draws an analogy between cooking chalcone pizza and the various pizza types as derivatives of the chalcone pizza; also, the student correlates the different reagents used in synthesis as a topping on the pizza.

Students are often extremely creative with their work and place their compounds in the most unusual of circumstances while still utilizing sound scientific principles to convey their understanding. For example, a student has written a chemistry blog highlighting the life of their chalcone.

> *"Volume 1: Benzaldehyde and his wife, Acetophenone, are the ultimate power couple! Their fearless love connection is something to seriously envy. They left with sodium hydroxide and ethanol for the Aldol condensation islands and just returned with a son! The little boy, Chalcone, is going to be a real force! We'll keep you guys posted on his growth and how he transforms.*
>
> *Volume 2: Chalcone is growing up so fast! He just added two bromines and his weight increased so much! It was all of that acetic acid that helped him grow.*
>
> *Volume 3: So, I guess Chalcone has been getting into some mischief lately. The word is he drank some of his dad's aged Hydrogen Peroxide at a party and threw up all over his crush. Apparently the poor girl has a huge gasp on her face in the shape of an 'O' and now they are calling her Chalcone's Oxide.*
>
> *Volume 4: Oh Chalcone and his dibromide! He was going around town and got some potassium hydroxide. I guess he inhaled too much of it with of his favorite hydroxylamine because he has been sneezing up isoxazole dust all day. Let's wish him a fast recovery!*

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Volume 5: Again, we have found Chalcone with potassium hydroxide and hydroxylamine. Someone needs to have him admitted. He thinks he is clever at hiding it, but we spot that isoxazoline flaking from his hair!

Volume 6: I know it has been a while guys, but great news! Chalcone reportedly got some treatment for his condition at the acetic acid clinic! He even got into phenyl hydrazine university and is going to graduate soon. He said he is on his way to becoming one of the best N-phenyl pyrazolines on the planet! Good luck to our #1 man!"[11]

We have seen that this creativity allows students to put the reactions in an alternate perspective, which helps them comprehend the chemistry and communicate the information more effectively. The majority of students who register for organic II at GSU are nonchemistry (biology and premedical among others) who must complete the required chemistry courses and many simply document their experiences of the lab for their introductions in their own words.

*"**Organic as I knew it**: Ever since I declared Biology as a major, I heard the horror stories of organic chemistry. Everyone was right. Not only was it horrible but boring and super hard. Three years later, I was done with both organic chemistry lectures; however, there I was, sitting in yet another organic chemistry class, but this time, it was the lab. Having no interest in learning more organic and sitting in lab for 4 h 2 days a week, I was startled when a chipper, short man walked in the room yelling, 'This will be fun! Organic is fun! Lab is fun! You will have fun!' My immediate thought, 'No way.' Lab is not fun and organic was definitely not fun, but that little man, Dr. Henary, insisted it would be.*

Then he went on and on about this compound called chalcone. Not only did we have to make this compound correctly but we would use it to make five other compounds; three were required and two were optional. Dr. Henary told us the yellow-colored chalcone would be prepared from an aldol condenation reaction between benzaldehyde and acetophenone using sodium hydroxide in ethanol. Once chalcone was synthesized, it underwent bromination in acetic acid to make the colorless chalcone dibromide. Using my dibromide chalcone, addition of hydroxylamine hydrochloride under basic conditions would create isoxazole. Since I was quick to make all required compounds, my optional compounds were next in line. I choose to synthesize isoxazole from isoxazoline because Dr. Henary insisted we would all enjoy it with his normal excited vigor. Then I had 4-hydroxypyrazoline from my chalcone oxide. Once each compound was complete, Dr. Henary insisted we gather all known information by doing a comprehensive literature search using various databases, run IR, NMR, melting point, and calculated percent yield. Every time Dr. Henary taught us something new, he would run up to the seats and say "Understand class!?" or "Is it easy? Say yes!" I grew to love that he needed our confirmation that we understood what he was telling us. If one person did not understand, he took it as everyone not understanding and re-explained the material. I began to understand organic chemistry and, in the end, the short chipper man yelling at the beginning of the course was correct—organic chemistry IS fun, even for this once disinterested biology major."[12]

We can see through students' creativity that they become excited about the course and the organic chemistry course material.[10−12] These lab report introductions are followed by thoughtful organic chemistry discussions detailing proposed reaction mechanisms, NMR explanations, and complete experimental protocol for their final compounds. In order to gain the students' perspective, we developed a survey that would offer some insight into how well it works for them.

■ STUDENT EVALUATIONS

We wanted to find a way to see if the creative reports actually served the intended purpose in the students' perspective. To do this, we prepared student evaluations (as shown in Figure 1), which were given to the students to be completed anonymously. The evaluations contain a variety of questions, both open-ended and those that required the students to declare a number (1−5) corresponding to how much they disagreed (1) or strongly agreed (5) with the statement. The evaluations were given to the organic II class offered at GSU and were then collected for review.

Special attention was given to the results for questions 1, 2, 3, 7, and 8 because they offered the most insight into the students' opinion regarding the effectiveness of this course. We found that when students prepared a creative report, both their excitement and understanding of the material increased dramatically as a result. The average response to question 1 was a 4.5 and to question 2 was a 4.8, indicating that the creative report made them more eager to learn and gave them a deeper understanding of the material. In addition, the standard deviation for questions 1 and 2 was 1.1 and 0.6, respectively. The students who selected 4 and 5, agree and strongly agree, as their response fall within one standard deviation unit from the mean response. Those that chose no impact, answer selection 3, do not fall within this range and therefore are considered outliers. The replies to questions 3 and 7 suggest that every student came out of the class more prepared and more knowledgeable of the course material than they would have had they not taken the organic II lab at GSU. The average scores were 4.5 and 4.4, respectively, on the student evaluations, which indicate an increase in students' confidence in their ability to conduct organic chemistry research. Even more impressive, 47% of the students who took organic II lab consider themselves more likely to consider a career related to chemistry despite the fact that >80% of the registered students are nonchemistry majors. We have seen that students enjoy and benefit from preparing the creative report; however, we decided to explore quantitation of this technique relating to student performance on the lab report and final examination with respect to their performance in the class prior to writing their creative report.

■ GRADE DISTRIBUTIONS

We recognize that subjectivity may skew data and therefore hold each final laboratory report to the same rigorous grading rubric depicted in Figure 2A, which accounts for one-third of the overall course grade. Taking this into account, writing the creative reports allow students to more accurately discuss the chemical topics that must be thoroughly explained throughout the report. The grade distribution on the final report shown in Figure 2B was taken from GSU organic II laboratory instructors from the years 2007 to 2012 and includes a diverse array of students such as nonchemistry major students pursuing a degree to enter professional schools.[5] The data indicate that 85% of students registered for the laboratory course received either an "A" or "B" letter grade on their final laboratory report for the respective years (87.4 average, standard deviation of 5.9). The high-grade

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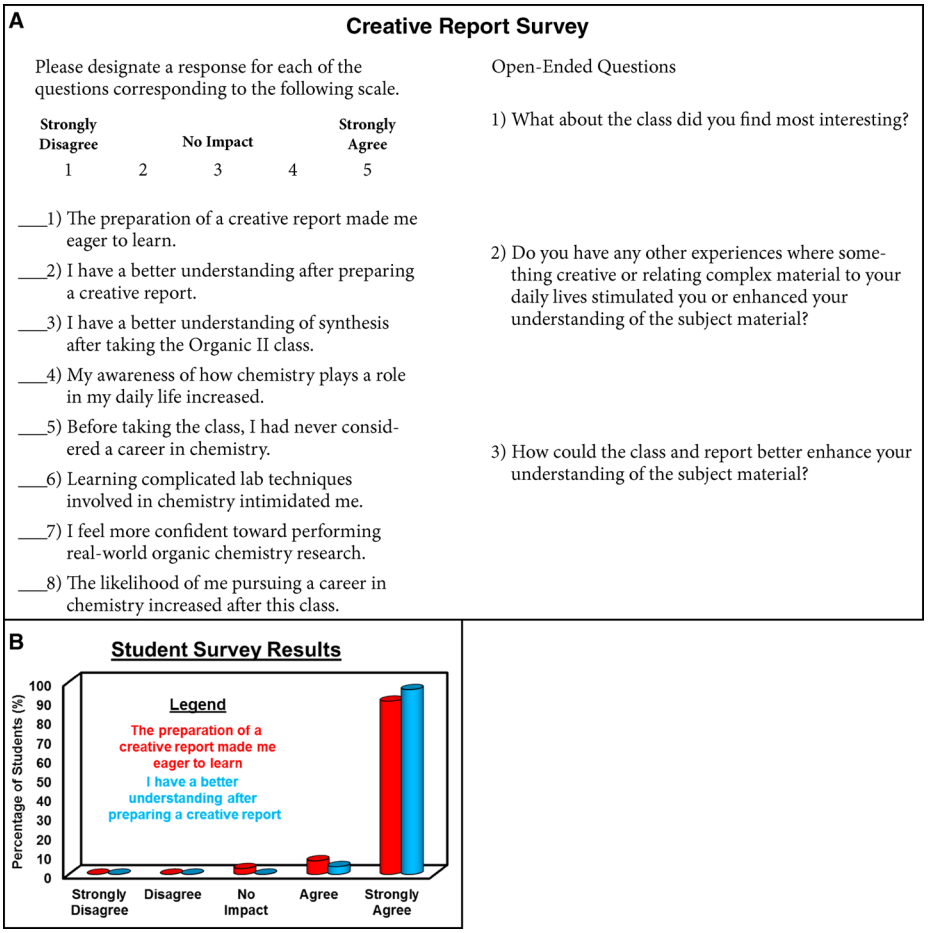

Figure 1. (A) The survey given to organic chemistry II students after their final exam and after having completed their final report. (B) Compiled student response (in %, based on 80 students) to questions 1 and 2, concerning the creative report.

distribution suggests a high level of enthusiasm developed during the duration of the course.[5] A small percentage (~13%) of the students receive "C"s, and a small number of students (~2%) receive grades lower than that of a "C". In comparison, the grade distribution for the same years was tallied for those classes that were not given the option of writing a creative lab report (77.2 average, standard deviation of 7.0). Only 59% of these students received either an "A" or a "B" letter grade, whereas a more substantial number of students (27%) received a letter grade of "C" and almost 14% of the students received a "D" or lower. In the final grade determination, the professors do not manipulate the distribution of grades to fit an overall curve either with or without the creative report further indicating the success of our creative method. It should be noted that every student, whether they wrote a creative lab report or a traditional lab report, participated in the same laboratory projects and were presented the same lecture information from identical laboratory manuals throughout the semester. The data shows that the students who wrote the creative lab report scored on average higher for their laboratory reports than those who did not, lending to the implication the creative lab reports, being the only difference from one class to the next, were the primary cause for this change. Although the laboratory report grades are not their final grades for the overall class, they are a strong indicator of the students overall success. These reports give the most insight in to whether or not the students grasped the material and were able to analyze and make sense of the data they received after each experiment.

The grade distribution from 2007 to 2012 suggests that the method of having the students write a unique and enjoyable, yet scientifically accurate, laboratory report works well for students. Although the reports contain informal material, they are still of high scientific quality at the undergraduate level and demonstrate a level of scientific understanding unparalleled by their formal report counterparts due to the ability to relate to their unique interests. The letter grade and corresponding percentile are A (90−100%), B (80−89%), C (70−79%), D (60−69%), and F (0−59%), and a W represents students who withdrew from the course.

Throughout the semester, students are given daily quizzes that reveal their respective understanding; correspondingly, we have noticed that students commonly improve upon their semester-long quiz average on the final laboratory report. The marked improvement is more significant for those who prepare a creative report with most students receiving 12% point or higher grade improvement from their semester long work. Additionally, because students begin working on their final report before the final exam, we see an improvement on the final exam for students who prepare a creative report. We attribute this increased success to the ability of students to relate to the course material through writing a creative introduction. We can see that the incorporation of a creative introduction−writing pedagogy has helped students write higher quality reports and increase overall performance on the final examination.

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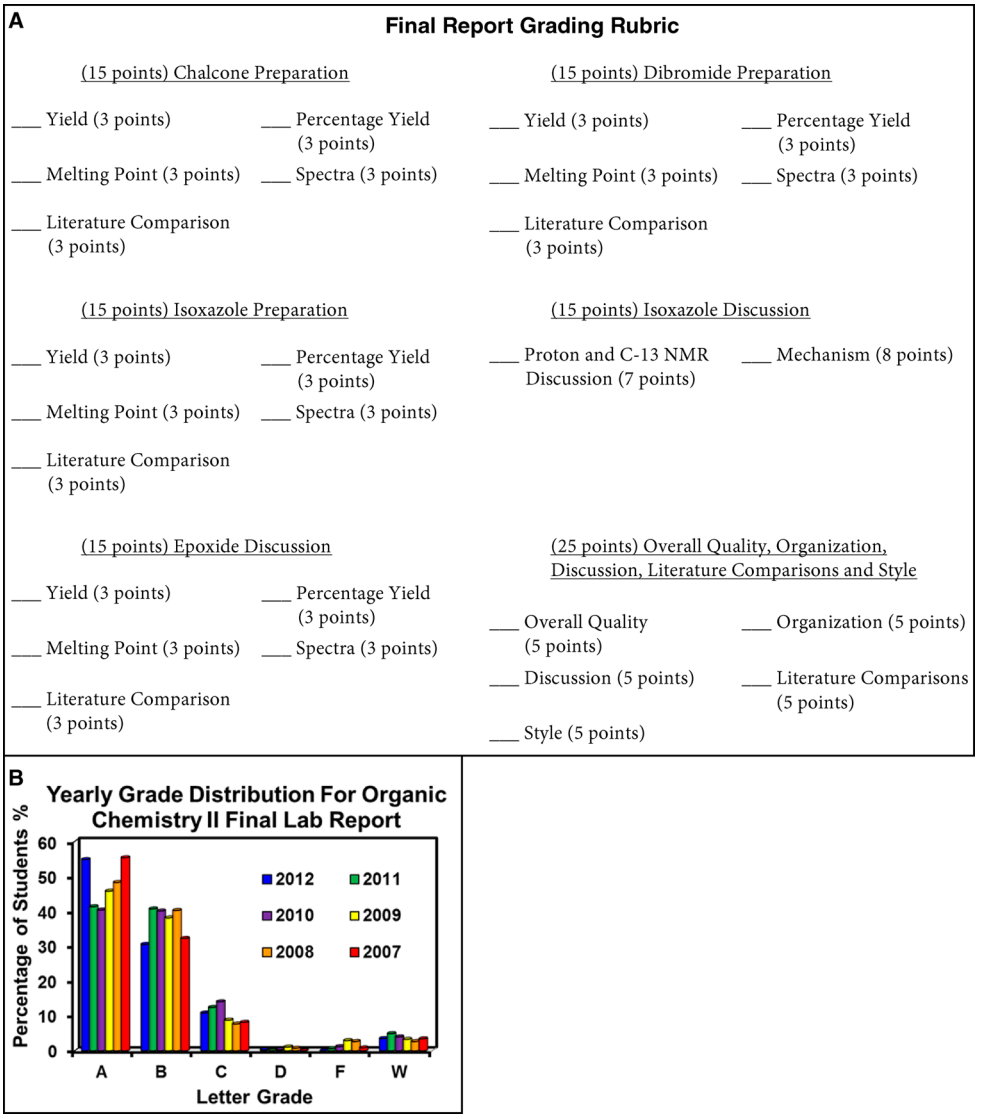

Figure 2. (A) The grading rubric applied to all organic II reports to standardize the grading process and remove subjectivity and (B) the grade received on the lab reports each year from 2007 to 2012, showing that students invest time when allowed to be creative.

INSTRUCTOR FEEDBACK

Several professors at GSU teach this particular course and about half (4/7) of the professors stress the importance of preparing a creative introduction to help visualize chemistry in students' own terminology. Some chemistry instructors are initially skeptical to the success of this pedagogy; however, after seeing the positive results from this program they begin altering their perspective. The professors who instruct this class are very positive about the implementation of creative-introduction preparation and one perspective is documented below.

> *"The majority of students taking organic chemistry II lab tend to be more excited about this lab compared to organic chemistry I laboratory. They enjoy the challenge of making different compounds. The most exciting part is when they have to write a lab report and I ask them to select their own title and be creative in their introduction. Students come up with very interesting titles such as 'Six Compounds, Six Weeks, One Cook', 'The Many Faces of Chalcone', 'Miracles of Chalcone', and 'From One Molecule Births Many: The Synthesis of 5'. Many of these students write excellent introductions (and overall reports) resulting in excellent letter grades (A). We also have students who just go straight to the point and remain entirely scientific. The joy and reward of teaching is when you see that students have enjoyed the class, as indicated by their creative titles, and the excellent grades from their creative yet scientific reports, which in many cases correlate with the overall grades."*
> *—Dr. Joan M. Comar, Senior Lecturer of Organic Chemistry and Co-Director of Undergraduate Studies*

Dr. Comar's remarks show the success of this program and other professors, including Dr. Keith Pascoe, strongly agree. Dr. Pascoe has extensive experience in undergraduate education and has notices a marked improvement after the implementation of the creative-introduction program.

> *"The organic chemistry faculty at Georgia State University has explored ways to motivate and inspire undergraduate students toward the practical component of the course. I have been a part of the faculty here at GSU for the past 16 years and have been part of this vigorous discussion. One novel approach that we have adopted was an idea suggested by Prof. Maged Henary, the faculty member with the responsibility for the organic chemistry II practical program.*

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Dr. Henary suggested that we should give students freedom when preparing the introduction of the final laboratory report and to use a 'creative approach'. I have suggested this to my students and was pleasantly surprised at how passionate the students were about this. Several very creative and humorous introductions were written with a great deal of scientific understanding interwoven throughout. Some of these introductions were great fun to read. Students used day-to-day experiences to express how they had synthesized their target molecules. We had very creative titles and stories, for example, 'Tour de Synthesis', 'When Benzaldehyde Dated Acetophenone', and 'The Children of The Chalcone Family'. We saw a noticeable growth in the effort made by students, especially premedical students, to get their report in on time, get comments on their introduction, and learn the chemistry behind their syntheses. This novel idea has definitely contributed to getting an increase in students' interest in the organic chemistry II practical class." —Dr. Keith O. Pascoe, Senior Lecturer of Organic Chemistry, Pre-Medical Advisor

This educational technique has become quite popular among professors and students; therefore, we suggest that other institutions consider adopting it for instruction, especially for nonchemistry majors who need an alternative format to help initiate scientific writing.

CONCLUSION

The methodology and planning behind the Organic II laboratory course offered at GSU is successful in providing students with the knowledge and techniques that can advance their chemistry education and careers. The students are able to break the norm of writing rigid, formal laboratory reports, where scientific terminology and structure will ultimately decide the students' grades. A common problem for students is being able to communicate the information they learned because students tend to rewrite the information in textbook terms. When students follow this simple procedure, they have trouble expanding and explaining different concepts. When students are able to be more creative in the manner in which they communicate the presented information, grades tend to be better, which translates to a better understanding and appreciation for the subject. For broadening the scope of this project, we are planning on having students in other lower-level classes implement this technique, and we are optimistic that we will observe similar effective results.

AUTHOR INFORMATION

Corresponding Author

*E-mail: mhenary1@gsu.edu.

Author Contributions

§These authors contributed equally to this work.

Notes

The authors declare no competing financial interest.

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