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Promoting the Diversity, Equity, and Inclusion in Organic Chemistry Education through Undergraduate Research Experiences at WSSU

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Abstract: Undergraduate research is well recognized as an effective high-impact educational practice associated with student success in higher education. Actively engaging students in research experiences is considered as one of the several high-impact practices by many agencies including the American Chemical Society. Developing and maintaining an active undergraduate research program benefits both the faculty and students especially those from under-represented minority groups (URM). The infusion of research experiences into undergraduate curriculum enables students from all backgrounds to develop independent critical thinking skills, written and oral communications skills that are very important for successful careers in "STEM" area. Several strategies and activities such as a Peer Mentoring Program (PMP), funded research activities, the infusion of research into organic chemistry labs, undergraduate professional development, research group meetings, presentations at regional/national conferences, and publishing as co-authors on peer-review papers are vital in creating a welcoming research group that promotes the diversity, equity, and inclusion in organic chemistry education. The experiences working on funded research projects, presenting their research data at conferences and publishing papers as co-authors will greatly increase the under-represented minority (URM) students' chance in landing a job or getting admitted into graduate/professional programs in STEM area.

Keywords: undergraduate research experiences; organic chemistry education; organic synthesis; high-impact practices (HIPs); the infusion of research into organic chemistry labs; diversity; equity; and inclusion (DEI); under-represented minority (URM) students; peer mentoring program (PMP)

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1. Introduction

Undergraduate research is well recognized as an effective high-impact educational practice that promotes student success in higher education. Undergraduate research is a learning activity that enriches students' undergraduate experiences. Undergraduate research is integral to the education of undergraduate students. Research has been valued as an important component of the overall education experiences of students. Participation in research and scholar activities broadens and deepens students' classroom learning and promotes the development of a range of skills that are important for their career development. Hands-on research experience and the experiences in conducting original research supports students' understanding of how to design investigations, how to develop the synthetic routes in organic synthesis, and how to implement different synthetic approaches. Undergraduate research also develops transferable skills such as critical thinking, problem

solving skills, independence, communication as well as team work that will benefit their career and life. The universities and colleges in the United States have been creating curricular engagement and support programs intended to promote undergraduate research because undergraduate research is considered one of the high impact educational practices. The United States federal agencies also recognized the importance of undergraduate research in the education of students and have put significant resources into promoting opportunities for undergraduates to engage in research. The National Science Foundation has allocated millions of dollars for undergraduate research programs such as the research experiences for undergraduates program (REU program). The National Institute of Health has AREA grand or R15 mechanism that provide funding for faculty mentored undergraduate research at primarily undergraduate institutions (PUIs). Undergraduate research plays an important role in an excellent and rigorous undergraduate chemistry curriculum [1,2]. Engaging students in research experiences is considered by the Association of American Colleges and Universities (AAC&U) as one of the five high-impact practices (HIPs) in higher education [3]. The universities and colleges in the United States have been creating curricular engagement and support programs intended to promote undergraduate research because undergraduate research is considered as one of the high impact educational practices. It has been widely recognized that personal interactions between research mentors and undergraduate students (the interactions via mentored research, research courses, working in a lab) have positive influences on undergraduate students' maturation and overall education experiences. The infusion of research into undergraduate curricula is considered to be an urgent need in the undergraduate science community to connect faculty research activities to the curriculum in ways that will lead to a research-rich curriculum for students [4]. A recent AAC&U national survey of student engagement also showed that these high-impact practices had a more pronounced effect on the experiences of underserved students that include students from under-represented minority (URM), and students with relatively low ACT scores [5]. Another AAC&U study, "Assessing Underserved Students' Engagement in High-Impact Practices," offered further insights into how the cumulative effects of these high-impact practices (HIPs) influence perceptions of learning among students from diverse, underserved groups [6]. The Department of Chemistry at WSSU has a history of valuing the importance of undergraduate research via the integration of research into the curriculum in chemistry at WSSU. [2] The guided inquiry laboratory experiments have also been implemented to improve the learning outcome of students especially those who are in the under-represented minority (URM) [7–9]. Undergraduate research experience is also highly recommended and valued by the American Chemical Society. Indeed, the American Chemical Society guidelines and evaluation procedures for a bachelor's degree in chemistry programs recognize the importance of undergraduate research, and it was stated that "undergraduate research allows students to integrate and reinforce chemistry knowledge from their formal course work, develop their scientific and professional skills, and create new scientific knowledge" [10]. A recent study by UT Austin researcher, Dr. Mervis, also showed that "genuine research keeps students in science" [11]. Although the importance of undergraduate research experiences has been widely recognized, there are still challenges in recruiting, motivating, and retaining underserved undergraduate students in research and eventually in the "STEM" area as the choice of careers. Undergraduate research experiences, when effectively executed, could be an ideal vehicle in improving student learning outcomes, promoting the diversity, equity, and inclusion in "STEM" education. Several strategies and activities including a Peer Mentoring Program (PMP), funded research activities, the infusion of research into organic chemistry labs, undergraduate professional development, research group meetings, presentations at regional/national conferences, and publishing because co-authors on peer-review papers are vital in creating a welcoming research group that increase the engagement of individuals from under-represented groups in the chemistry enterprise, and decrease the barriers experienced by these individuals in the discipline.

It has been reported that developing and maintaining undergraduate research is beneficial to all stakeholders including the students, faculty mentors, the university, and the society at large [12]. In recent years, the importance of research performed at primarily undergraduate institutions (PUIs)—including our university, Winston-Salem State University (WSSU)—has been gradually recognized [2]. The Council of Undergraduate Research (CUR) has done an excellent job in promoting research opportunities for both students and faculty at primarily undergraduate institutions [13]. A recent funded NSF project—CUR Transformation Project (CUR-TP) aims to address the urgent need in the undergraduate science community to connect faculty research activities to the curriculum in ways that will lead to a research-rich curriculum for students [4]. The Department of Chemistry at Winston-Salem State University (WSSU) is selected as one of 12 institutions and 24 departments to work on this project over a sustained period to conduct fundamental research on student, faculty, departmental, and disciplinary influences on the process of integrating and scaffolding undergraduate research experiences throughout the curriculum. I am the department CUR-TP team member and have been actively infusing research into the Organic Chemistry II lab at WSSU. For under-represented minority (URM) students at WSSU, the access to quality research experiences is even more important and vital in promoting the diversity, equity, and inclusion in "STEM" education. Several strategies and activities such as a Peer Mentoring Program (PMP) [14,15], funded research activities, CUR-TP project, the infusion of research into Organic Chemistry II lab, undergraduate professional development, research group meetings, presentations at regional/national conferences, and publishing as co-authors on peer-review papers are key in creating a welcoming research group that promotes the diversity, equity, and inclusion in Organic Chemistry education at WSSU.

2. Funded Research Activities

The Importance of Funded Research Activities

In the past several years, our research group has kept growing thanks to the very general financial supports from federal funding agencies including NSF and NIH. Undergraduate students working in our research group have been supported as research assistants with grants from NSF HBCU-UP programs and NIH RISE program. These research assistantships allow the students with minority background to focus on the research without the distraction of off-campus jobs. For example, in the past 4 year, 27 WSSU undergraduate students have been offered research assistantships in my research group, with 5–8 students each year. All these students are from very diverse backgrounds and are paid for up to 20 h/week from my research funding or up to 15 h/week from NIH RISE program. During the COVID-19 pandemic, 7 WSSU undergraduates have been paid through undergraduate research assistantships during the 2020–2021 academic year. Students were able to keep up face-to-face research activities wearing masks with social distancing. These funded research activities have provided valuable research experiences, as well as a stable financial support to many students, while keep them in the chemistry program. The funded research activities are vital in creating a welcoming research group that increases the engagement of individuals from under-represented groups in the chemistry enterprise, decreases the barriers experienced by these individuals in chemistry, and promotes the diversity, equity, and inclusion in chemistry education.

3. Results and Discussion

The impact of funded research activities: Since 2016, two projects from our research group have been funded by NSF HBCU-UP programs—NSF HBCU-UP Research Initiation Award (RIA) program and HBCU-UP EiR award. The Research Initiation Award (RIA) is focused on the "Development of Carbon-Carbon Bond Forming Strategies in the Synthesis of O-, N-Heterocycles". Additionally, the Excellence in Research (EiR) award is focused on "the Unlocking of the Synthetic Power of Regioselective and Stereoselective Carbon Carbon Bond Formations for Multicomponent Reactions in Heterocycle Synthesis". These two

projects aim to develop innovative synthetic approaches to heterocycles. At the same time, the NIH RISE program also provided financial support for two to three undergraduate students from minority group each year in my research group since 2016. Overall, these federal grants have provided financial support for more than 20 under-represented minority students, allowed them to focus on undergraduate research projects without the distraction of off-campus jobs and kept them in the chemistry program. These high-quality genuine research experiences have significant impacts on students' education and career paths. Indeed, the undergraduate research experience may be one of the most important factors in affecting students' choice of majors and career paths. Among students who worked in my research lab, many students have gone to graduate schools and some landed high-paying jobs in the chemistry field after graduation from WSSU (see the Supporting Information). The success stories of students in our research group demonstrated the importance of the high-quality genuine research experience in stimulating the interest of under-represented minority (URM) students in organic chemistry education, keeping them in the program, and promoting the diversity, equity, and inclusion in organic chemistry education (see SI).

3.1. Results from Funded Undergraduate Research Projects

3.1.1. Funded Research Project 1

Rhodium catalyzed 1,4-conjugate addition to *N*-Boc-4-pyridone **A1**. Our initial investigation showed that when 3 mol% of R-BINAP was used as ligand, 1,4-adduct **A2** can be attained in good chemical yields and excellent ee (Figure 1). Both electron-withdrawing and electron-donating substituents on aromatic ring of arylzinc reagents worked well and afforded 1,4-adducts in excellent yields (up to 91%) and ee (up to 96%). It was found for the first time that strong electron-withdrawing groups on an aromatic ring also worked well, and some of these results were published with four undergraduate students with minority background as co-authors [16]. We also discovered the remarkable accelerating effects of Rh(I)-BINAP **B2** complexes on the *N*-Boc-4-pyridone **A1** when combined with TMSCl.

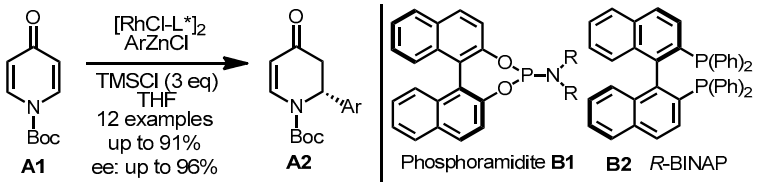

Figure 1. Results from Prior NSF Support—Conjugate Addition to 4-Pyridone (Molecules **2017**).

3.1.2. Funded Research Project 2

The development of conjugate addition to thiochromones. We also developed the first diarylcuprate conjugate addition to thiochromones A3 and provided a rapid entry into an important class of S-heterocycle—thioflavanones A4 in excellent yields (Figure 2) [17]. Three WSSU undergraduate students from a minority group as well as two high school student interns contributed to the reaction development and are coauthors for this publication [15]. We also further expanded the scope of the conjugate additions to thiochromones by taking advantage of the ease of preparation and the broader scope of Grignard reagents compared to other organometallic reagents such as organolithium reagents. This approach allows the synthesis of 2-substituted thiochroman-4-ones A5 that were otherwise unavailable with other organometallic reagents [16]. The Cu (I) salts can be reduced to 10% and the reactions can be carried out at milder reaction conditions (Figure 2). The 1,4-adducts attained can be utilized for additional synthetic applications for bioactive S-containing heterocycles [18,19]. These NSF grants allow the PI to purchase instruments and chemicals, set up a research lab and develop a sustainable active research program for under-represented/underserved minority (URM) students at WSSU. These funded research activities are vital in increasing the engagement of individuals from under-represented groups in the chemistry enterprise, decreasing the barriers experienced by these individuals in chemistry, and promoting the diversity, equity, and inclusion in chemistry education.

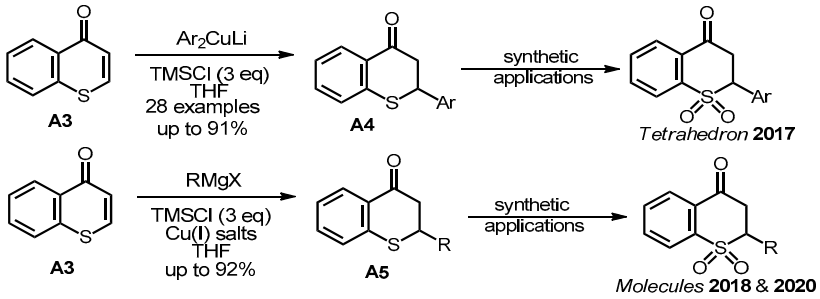

Figure 2. Results from Prior NSF Support—Conjugate Addition to Thiochromones.

3.2. The Importance of Undergraduate Research—The Impact on Undergraduate Students' Education and Career Path

The impact of undergraduate research on students' education and career paths—Where Have Students Been After Working in Dr. Guo's Lab? Undergraduate research experiences have a significant impact on students' education and career path. Indeed, the undergraduate research experience may be one of the most important factors in affecting students' choice of majors and career paths. Among students who worked in my research lab, many students have gone to graduate schools and some landed high-paying jobs in the chemistry field after graduation from Winston-Salem State University (see SI). Since 2017, 10 (91%) out of 11 graduates either found a job in the chemical industry or were accepted into graduate/professional program (see SI, Table S1). Under-represented minority (URM) students accounted for 91% (10 out of 11 students) of these graduates. Among them, 7 (64%) out of 11 went to graduate school/professional schools while 3 students (27%) found jobs in the chemistry industry. The GPAs of students who went to graduate schools are ranged from 3.0–3.95. Among the students who went to graduate school, three (43%) out of seven have a GPA of 3.0–3.2, two (29%) have a GPA of 3.3–3.5, while two (29%) have a GPA of 3.8–4.0. Three students with lower GPA (<3.2) also did well on the funded research project, published papers as co-authors and were accepted into graduate schools. These achievements and the career paths of students after graduation from WSSU further demonstrates the significant impact of undergraduate research experiences on students' educational and career path (see SI). The success stories of students in our research group demonstrated the importance of the high-quality research experience in stimulating the interest of under-represented minority (URM) students in organic chemistry education, keeping them in the program, and promoting the diversity, equity, and inclusion in organic chemistry education (see SI). The student success always motivates me to strive to provide innovative high impact research experiences in organic synthesis to STEM undergraduates, from under-represented groups, and set them on the road to become scientists and other professionals in the "STEM" field. The success of these students, especially those of the under-represented minority (URM) students, further demonstrates that these strategies and activities including a Peer Mentoring Program (PMP), funded research activities, undergraduate professional development, research group meetings, presentations at regional/national conferences, and publishing as co-authors on peer-review papers are vital in increasing the engagement of individuals from under-represented groups in the chemistry enterprise, and decreasing the barriers experienced by these individuals in the chemistry field.

3.3. Creating a Welcoming Research Group That Promotes the Diversity, Equity, and Inclusion in Organic Chemistry Education

In the past several years, my research group has gradually grown into one of the largest research groups with undergraduate students in the Chemistry Department. We have learned some key strategies in creating a welcoming research group that promotes the diversity, equity, and inclusion in organic chemistry education at WSSU. First, our research group welcomes students from diverse backgrounds. Among the 27 students in the past four years, 6 are male (22%), 21 are female (78%), and 23 are from under-represented groups

(89%). Students' GPAs typically ranged from 3.0–3.95. The diversity in our research group is vital in promoting a sense of belonging for all students from all backgrounds. Second, students' achievements and placements after graduation are key in recruiting new research group members. Early involvement of students in research is a viable strategy to excite under-represented minority (URM) students and keeping them in the chemistry program. Some students joined my research group as early as the sophomore year, continued to work in the group for three years, and went on to find jobs or graduate/professional schools. The students' achievements and the placement of students after graduation is one of the best tools in recruiting new students. Students typically have presented their research findings (oral and/or poster presentations) on campus, regional (SERMACS meetings) and national conferences (ACS national meetings, ERN, ABRCMS) before graduation. Most students also published one or multiple peer-reviewed journal papers in the field of organic chemistry before they graduated. These accomplished students are excellent role models for students who are interested in joining our research group. Students, who enjoyed working in the group and have very positive experiences, also help spread the words and recruit more students to our group. Third, the effective mentoring played a vital role in the successful career development of undergraduate students. Besides the faculty mentor, we also developed and implemented a Peer Mentoring Program (PMP). Peering mentoring has been designed to improve undergraduate STEM retention [20,21]. Under the "PMP", each new group member is paired with a senior student mentor (Peer Mentor), who has typically worked for more than one year in our research group and gained extensive experiences in research. The "PMP" is very effective in generating student excitement, promoting critical thinking, teamwork, as well as the leadership skills. Under the "PMP", the new students learn side by side from the peer mentors while the peer mentors gradually grown into independent researchers and are ready to go to graduate/professional schools or industrial jobs. Among four students who have served as Peer Mentoring Program "PMP" mentors, three of them are currently enrolled in PhD, PharmD program, and one is employed in the chemistry field (see SI). As the faculty mentor and the PI, my goal is to build a friendly research group that welcomes and inspires students from diverse backgrounds.

3.4. The Importance of Undergraduate Research—The Students' Perspectives

Undergraduate research is integral to the education of undergraduate students. Research has been valued as an important component of the overall education experiences of students. Participation in research and scholar activities broadens and deepens students' classroom learning and promotes the development of a range of skills that are important for their career development. Undergraduate research also develops transferable skills such as critical thinking, problem solving skills, independence, communication as well as team work that will benefit their career and life. It has also been widely recognized that personal interactions between research mentors and undergraduate students (the interactions via mentored research, research courses, working in a lab) have positive influences on undergraduate students' maturation, the overall education experiences. It has been shown that engagement in undergraduate STEM research would improve academic performance in students engaged in research compared to those who were not [22]. To evaluate the overall student experience of the undergraduate research experiences and CUR-TP project, a voluntary survey (see the Survey in the Supporting Information) was administered to the research students at the end of the semester. The survey showed that 90% of the participants found their projects very interesting and exciting. Moreover, 90% of the students strongly agreed or agreed that they understand the importance of heterocycles. More importantly, 90% of the students are very confident or confident in reporting results both in oral and written form. Additionally, 85% of the participants strongly agreed that they could identify themselves as scientists and are considering the graduate as an option when they graduate.

Some of the student comments directly taken out from the student survey as well as the student comments from faculty course evaluations on CUR-TP—the infusion of research into Organic Chem II lab—are presented here.

"CUR-TP is the best research class I ever had in my whole college career"

"I love CUR-TP project. This project allows students who doesn't have any research experiences to conduct meaningful research project"

"Working on the research project in Dr. Guo's lab motivated me to work harder". "I really enjoyed making new organic molecules"

"This was my first time doing research. I really enjoyed it and learned a lot for the CUR-TP project. I wish it could be more than 3 weeks"

"I love working with PMP mentor. My mentor has been very helpful in teaching me the lab techniques in Organic synthesis".

"I love working in the group. I felt welcomed by other members. My group members have been helpful".

"My PMP mentor got into PhD program. She has been very helpful and a great role model for me".

"The research experiences I had in Dr. Guo's research lab is very valuable. I have learned so much and I look forward to going to graduate school"

"Love working in the group even during the difficult time with COVID-19. I enjoyed research but wearing a mask in lab was not fun. The stipend from NSF funded research has been the stable income during COVID-19 pandemic"

"I enjoy serving as PMP mentor. Being a peer mentor reinforce the knowledge since I have to understand the concepts well in order to teach other students"

"We participated in the CUR Transformation project which was cool to do. It allowed students like me who haven't done research with professors to get hands on research experience."

"The CUR experiment was the best lab experience in my whole college education"

4. Conclusions

Undergraduate research experiences have a significant impact on students' education and career path. Undergraduate research also develops transferable skills such as critical thinking, problem solving skills, independence, communication as well as team work that will benefit their career and life. It has also been widely recognized that personal interactions between research mentors and undergraduate students (the interactions via mentored research, research courses, working in a lab) have positive influences on undergraduate students' maturation and overall education experiences. Indeed, the undergraduate research experience may be one of the most important factors in affecting students' choice of majors and career paths. Undergraduate research experiences are vital in increasing the engagement of individuals from under-represented groups in the chemistry enterprise, decreasing the barriers experienced by these individuals in chemistry, and promoting the diversity, equity, and inclusion in chemistry education. Several strategies and activities such as a Peer Mentoring Program (PMP), funded research activities, the infusion of research into organic chemistry lab, undergraduate professional development, research group meetings, presentations at regional/national conferences, and publishing as co-authors on peer-review papers are key in creating a welcoming research group that promotes the diversity, equity, and inclusion in organic chemistry education. Participation in research and scholar activities broadens and deepens students' classroom learning and promotes the development of a range of skills that are important for their career development. The experiences working on research projects and presenting their research data at conferences and publishing papers as co-authors will greatly increase the under-represented students'

chance of landing a job or being admitted into graduate/professional programs in STEM area. In conclusion, undergraduate research experiences are important and effective in promoting the diversity, equity, and inclusion in organic chemistry education.

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