Production and Characterization of Graphene and Other 2-dimensional Nanomaterials: An AP High School Inquiry Lab (Curriculum Exchange)

Mrs. Alison Lynn Fielding, Centennial High School, Boise, ID

Mrs. Alison Fielding teaches Advanced Placement Chemistry and College Preparatory Chemistry at Centennial High School in Boise, ID. She earned her BS in Earth Science Education from Boise State University in 2013 with a minors in Chemistry. She is currently pursuing a Masters of Science degree in STEM from Boise State University. In an effort to explore new pedagogical approaches she worked with Boise State University's Integrated NanoMaterials Laboratory as part of a Research Experience for Teachers in Materials for Energy and Sustainability where she developed a guided inquiry laboratory to introduce students to 2-dimensional nanomaterials. A devoted family woman and working professional, Alison has been married for 19 years and has 4 beautiful children. She is committed to her role as an educator and balances life and work by taking advantage of Boise's easy access to outdoor activities and sports.

Dale Brown, Boise State University

Dale Brown earned an M.S. in Physics from University of Illinois at Urbana-Champaign in 2011. Dale also holds a B.S. in Physics and a B.S. in Biochemistry with a minor in Mathematics from Northwest Nazarene University where he graduate Magna Cum Laude in 2010. Dale's current research focus at Boise State University includes investigating large-scale synthesis of 2-dimensional materials, experimental and theoretical investigations of their physical properties, and their practical applications in the space and nuclear industries. Dale is the past recipient of a Nuclear Regulatory Commission graduate research fellowship through the Boise State Nuclear Materials Fellowship Program and a current recipient of a NASA EPSCoR graduate fellowship.

Richard Livingston, Department of Mechanical and Biomedical Engineering, Boise State University

Richard Livingston is a senior at Boise State University, and will receive his B.S. in Mechanical Engineering. During his time at Boise State Richard worked for the Integrated Nanon materials Laboratory(INML) . While at INML Richard has aided in design of the universities first chemical vapor deposition system, and has implemented the labs capabilities for liquid exfoliation of two-dimensional materials. Out side of class and work Richard is student member of American Society for Mechanical Engineers (ASME), American Institute of Aeronautics and Astronautics (AIAA), vice president of Boise States Rocket Club, and an active member of Boise States Aerospace Club. He is also an active mountain bike and motocross rider.

Mr. Curtis Heishman, Boise State University

Curtis Heishman attended Davis & Elkins College in Elkins, WV where Dr. Floyd Wiseman mentored and sparked an interest for him in conducting chemistry research. He attended a chemistry REU program at Boise State University with Dr. Eric Brown. There they conducted research of the bioinorganic synthesis of compounds replicating the mechanism by which carbonic anhydrase processes greenhouse gasses. Most recently, Curtis has worked with Dr. Dave Estrada and Dr. Kevin Ausman conducting research of 2D nanoparticles as part of a materials science REU at Boise State. He is currently continuing that research while working towards an undergraduate degree in chemistry at Boise State.

Dr. Louis Nadelson, Utah State University

Louis S. Nadelson is an associate professor and lead researcher for the Center for the School of the Future in the Emma Eccles Jones College of Education and Human Services at Utah State University. He has a BS from Colorado State University, a BA from the Evergreen State College, a MEd from Western Washington University, and a PhD in educational psychology from UNLV. His scholarly interests include all areas of STEM teaching and learning, inservice and preservice teacher professional development, program evaluation, multidisciplinary research, and conceptual change. Nadelson uses his over 20 years of high

school and college math, science, computer science, and engineering teaching to frame his research on STEM teaching and learning. Nadelson brings a unique perspective of research, bridging experience with practice and theory to explore a range of interests in STEM teaching and learning.

Dr. David Estrada, Department of Materials Science and Engineering, Boise State University, Boise, ID, USA

David received his Master of Science in Electrical Engineering from UIUC in 2009, and his Doctor of Philosophy in Electrical Engineering at UIUC in 2013 under the direction of Prof. Eric Pop. David then joined Prof. Rashid Bashir's Laboratory of Integrated Bio Medical Micro/Nanotechnology Applications as a Visiting Postdoctoral Researcher before moving to the Materials Science and Engineering Department at Boise State University. David is a member of Tau Beta Pi, the Institute of Electrical and Electronics Engineers, the Materials Research Society, the American Chemical Society, the American Physical Society, and the Society of Hispanic Professional Engineers. He is the recipient of the NSF, NDSEG, SURGE, and Micron Graduate Fellowships. His work has been recognized with several awards, including the Gregory Stillman, John Bardeen, and Lieutenant General Thomas M. Rienzi graduate research awards. His research interests are in the areas of emergent semiconductor nanomaterials and bionanotechnology.

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According to the National Nanotechnology Initiative, there is high expectation that developments in nanotechnology will lead to new job creation and become an economic driver of emerging markets for nano-enabled products. In light of the potential economic impact, it is imperative that we support the development of new high school curricula as a way to motivate students towards pursuing education and careers in nanotechnology. Recent advances in nanomaterials processing, particularly 2-dimensional (2D) nanomaterials synthesis,[1] present the opportunity to integrate nanotechnology curriculum into high schools in safe and relatively inexpensive manners.

In our work, we present an Advanced Placement (AP) Chemistry Inquiry Laboratory (CIL) targeting 11th and 12th grade high school students. The CIL is being implemented at Centennial High School in Boise, Idaho and in partnership with Micron Technology, Hewlett Packard, and Boise State University. The CIL is aligned to National College Board requirements for AP Chemistry courses as well as Next Generation Science Standards. The laboratory is designed to encompass five hours of time, including teacher preparation, pre-laboratory activities, materials synthesis, and a field trip exposing students to careers in STEM. The CIL will be performed in teams of 3 to 4 students, highlighting its easy adaptability to other STEM related courses.

Figure 1: 2D nanoflakes suspended in a solution of isopropanol and deionized water.

Students involved in the CIL will explore the intersections of chemistry, physics, materials engineering, and electrical engineering by performing shear exfoliation of layered crystals,[2] characterizing the optical and electrical properties of their nanomaterials, and exploring real world applications by designing an electronic device such as a thermistor.[3] Figure 1 illustrates solutions of 2D nanoflakes which will be produced as part of this CIL. The varying optical contrasts of the solutions highlight their unique electronic band structures. Students will be tasked with designing materials analysis protocols in order to identify 1 of 5 unknown materials based upon its properties. Partnership with Hewlett Packard allows students to use a scanning electron microscope as part of their efforts, but is not necessary to complete the CIL.

The CIL was made possible by support through NSF award #1359344 and the Micron Technology Foundation. The CIL materials consist of 1) A comprehensive teacher copy of the laboratory investigation with timing, alignment to curriculum and answers to guiding questions; 2) A student copy of the laboratory investigation; 3) Student handouts for pre and post-lab assessments; 4) Video links that can be watched as a class or assigned as homework to strengthen student understanding; 5) Assessment rubrics. All materials will be available online through the Boise State Integrated NanoMaterials Laboratory at coen.boisestate.edu/inml.

[1] Nicolosi, Valeria, et al. "Liquid exfoliation of layered materials." Science (2013): 1226419.
[2] Paton, K. R., et al. “Scalable production of large quantities of defect-free few-layer graphene by shear exfoliation in liquids.” Nature Materials (2014): 13(6), 624-630.
[3] Yan, C., Wang, J., & Lee, P. S. “Stretchable Graphene Thermistor with Tunable Thermal Index.” ACS Nano (2015), 9(2), 2130-2137.