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Career development and project planning for emerging thermal analysis scientists

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Abstract Advances in science and technology are now at the heart of the global economy, but the number of students earning degrees in the sciences, technology, engineering, and math (STEM) fields has stalled. According to the National Association for Colleges and Employers (NACE), programs have been initiated nationwide to nurture interest in the sciences, including research competitions, co-ops and internships, and K-12 STEM education. Senior thermal analysis scientists are not only researchers, they are role models, mentors and teachers intimately involved in the recruitment and training of young scientists. The authors present guidelines for thermal analysis research project planning for high school students, undergraduate students and master's and doctoral candidates. Project planning includes developmentally appropriate techniques, methods, instruments, scope and significance. Case studies illustrate examples of short-term, concrete materials analysis projects tailored to younger student researchers, as well as master's level projects making significant contributions to the state of the science and innovative doctoral research. In addition to designing projects for students at all levels, senior thermal analysis scientists can use specific teaching and training techniques to help young scientists develop their abilities in the lab and at the podium.

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Introduction

Careers in science, technology, engineering, and mathematics—collectively known as STEM—are among the most rewarding and demanding career choices for young people. STEM careers often require continuous study of technical concepts from elementary school through advanced graduate work. In the twenty first century knowledge economy, STEM careers are expected to lead the way and thermal analysts have long been educators, researchers, and industry leaders in biology, chemistry, physics, health care, and materials science. In addition to meeting the next generation of technical challenges, thermal analysts face the challenge of attracting and retaining the next generation of the thermal analysis (TA) community.

The Bureau of Labor Statistics published a 2007 report on STEM careers [1] which compared the annual wages of STEM workers—$64,560—to those of all workers—$37,870. The total number of STEM occupations was projected to grow 22% by 2014 with a total number of job openings over 2.5 million. Despite the growing demand and high compensation for workers in these occupations, the number of bachelor's degrees awarded in STEM subjects has been flat over the past decade—with the exception of computer and information sciences, which has grown with the increases in the number of computer jobs available and employer preferences for works with degrees in computer science.

Like many STEM disciplines, TA faces challenges in recruiting and retaining new practitioners. Tanaka and

Koga [2] noted the wide use of TA in research, development and production and the lack of emphasis on TA education at the undergraduate level. They proposed an application of thermal analysis to studying solid-state kinetics in undergraduate chemistry courses. Hakvoort and Hakvoort [3] wrote in a similar vein to describe a weeklong TA course for undergraduates to expose students to the possibilities of TA through hands-on experimentation. Riga et al. [4] proposed a concentrated program of thermal tests to assist students in understanding structure and thermal property relationships. Wunderlich [5] expanded on the issue, writing that "Thermal analysis and polymers are two subjects in the field of chemistry and materials sciences that have not developed to the level commensurate with their importance." Wunderlich, along with Sørensen [6], proposed online delivery of TA education.

Since the publication of the Boyer Commission on Educating Undergraduates in the Research University's report, "Reinventing Undergraduate Education: A Blueprint for America's Research Universities" in 1998 [7], there has been a national emphasis on providing undergraduate research opportunities. Given the wide application of TA across academic disciplines, there are rich opportunities for integrating TA into undergraduate research programs, but the TA education literature lacks information about these opportunities. This paper presents examples of undergraduate research project development in the Riga Research Team at Cleveland State University (Cleveland, Ohio), suggests some preliminary guidelines, and invites other TA researchers, educators and practitioners to contribute to the ongoing conversation about how to excite students' interest in TA.

Independent research projects

Suga [8] identified an understanding of amorphous materials as an important frontier in TA research. Exploring structure–property relationships in amorphous and crystalline pharmaceuticals has been a focus of the Riga Research Team for the past decade, beginning with basic research into characterization of drugs and excipients, and growing into development of new methods for quantification of crystalline and amorphous content in pharmaceutical materials.

In 2004–2005, an undergraduate research project was designed to investigate polymorphic drug characterization using thermal and analytical techniques [9]. The cardiovascular drug nifedipine was chosen for the study because it is known to exist in three polymorphic forms—two crystalline and one amorphous. The research objectives were to:

1. Prepare the two crystal forms of nifedipine: Form II (1,4-dioxane solvate) and form III (amorphous-crystalline form). Form I is the commercially available product.
2. Characterize the polymorphic forms by differential scanning calorimetry (DSC), dielectric analysis (DEA), powder X-Ray diffraction (PXRD), scanning electron miscroscopy (SEM), Raman spectroscopy, and macro-photography.
3. Develop a unique thermal analytical method for evaluating polymorphic solids by electrical conductivity analysis [ECA] from 10^{-3} to 10^{8} (conductivity units) pS/cm.

That research, along with a second project investigating the polymorphic drug tolbutamide [10] led by another undergraduate student, was presented by the undergraduate student at a national conference on thermal analysis in September 2005 as a podium presentation at the conference and manuscript on the conference disc.

A third project begun in 2006 evaluated the essential physical–chemical properties of D and L amino acids by thermal and analytical methods [11], including DEA, thermogravimetric analysis (TGA), and DSC, along with PXRD. This study used the ECA method developed in the previously cited research to determine amorphous versus crystalline content. Other physical properties recorded include AC electrical conductivity (pS/cm) profiles, formation of charge transfer complexes, melting temperature/range, moisture loss (w %), recrystallization, and activation energy for the electrical charging process. The electrical conductivity of the samples was impacted by the moisture content and the amorphous–crystalline composition. This research was presented as a podium presentation at an American Chemistry Society Meeting-in-Miniature in Northeast Ohio in March 2007.

Each of the three projects were completed in an academic semester (3–4 months) by a team of two to three undergraduate researchers working under the direct guidance of an adjunct professor of chemistry and industrial pharmacy.

In 2008, the amorphous–crystalline characterization project morphed into a master's student mini-project investigating the crystalline and amorphous content in drugs by dielectric analysis [12]. The study included five drugs and one excipient (an inactive ingredient in drug formulations). The objectives of the study were to determine the amorphous and crystalline content in USP and commercial forms of the drugs, determine the standard electrical conductivity profile with transition temperatures and correlate the DEA with DSC melting and other phase transitions. The results of this work were presented in a poster at a graduate student research symposium in April 2009.

In 2010, the project was expanded into a PhD candidacy proposal with the goal of developing a novel and efficient thermal analytical method to accurately quantify crystalline and amorphous content in pharmaceutical solids using a combined DEA and DSC method. The thesis will also develop a theory base for the method, including predictive relationships and equations.

Discussion

A review of the literature reveals many benefits of engaging in undergraduate research [7, 13–21]:

- Increased interest in STEM careers.
- Increased persistence in pursuit of undergraduate degree.
- Increased pursuit of graduate education.
- Gains in skills carrying out research.
- Gains in skill acquiring information.
- Improved public speaking abilities.
- Promotion of STEM careers for members of underrepresented groups.
- Increasing the retention rate of minority undergraduates.
- Increasing the rate of graduate education in minority students.

Along with these benefits come challenges in recruiting and retaining undergraduate researchers [7, 17, 18, 22]:

- Recruiting students to participate in research opportunities.
- Designing and implementing successful undergraduate research projects.

Fig. 1 Sample research learning contract

Research Learning Contract

To: [Student Name] [contact information]
From: [Faculty Member] [contact information]
Date: [Date]
Subject: Independent Study with [Faculty Member]
[Independent Study Credit Hours] [Semester/Academic Year]
[Research Topic/Title]

BRIEF PROJECT DESCRIPTION

PROJECT OBJECTIVES

PERSONAL LEARNING OBJECTIVES

TASKS

EVALUATION

Signed by: ______________________ on ____________
Student Date

______________________ on ____________
Faculty Member Date

- Overcoming undergraduate students' lack of knowledge.
- Overcoming undergraduate students' lack of confidence.
- Balancing time commitments (classes, work, study, extracurricular activities).

Based on the review of the literature [7, 13–36] and the experiences with undergraduate students in the Riga lab, we have developed a list of 10 best practices for undergraduate research.

1. *Provide incentives for research participation.* Incentives could include course credit or paid employment.
2. *Form research teams of two or three students.* It can be especially effective to partner first- and second-year researchers with older peers. This approach fosters team-based problem-solving and allows coordination of student schedules to meet the needs of the research project—the burden is not on one student to be present for all stages of the research.

Fig. 2 Undergraduate Research Student Information Sheet (URSIS)

UNDERGRADUATE RESEARCH STUDENT INFORMATION SHEET

Section I. About You

Name:____________________________________ Anticipated Year of Graduation:__________

E-mail: ______________________ Phone: _________________ Major: ___________________

Class (circle one): Freshman Sophomore Junior Senior
Other (specify): _____________________________________

Career Ideas:
____
____
____
____

Section II. Coursework

Please indicate any courses you are now taking or have completed:

□ Introduction to Biology I
□ Introduction to Biology II
□ Anatomy & Physiology I
□ Anatomy & Physiology II
□ General Chemistry I
□ General Chemistry II
□ Physics I
□ Physics II
□ Biochemistry
□ Organic Chemistry I
□ Organic Chemistry II
□ Precalculus
□ Calculus
□ Statistics

Other upper-level or elective courses in science, math, technology or engineering:
____
____
____

Section III. Research experience & lab skills

Please describe any previous research experiences, including any methods, instruments or procedures used (for example, UV–Vis, titration, pH meter, balance, refractive index, etc.).
____
____
____

3. *Enact Research Learning Contracts*. These contracts should include personal learning and project objectives, deliverables and evaluation criteria. See Fig. 1 for a sample contract.
4. *Shared responsibility for research design*. Students and faculty members can negotiate the research design, collaborating in drafting the Research Learning Contract.
5. *Design concrete, short-term implementation-oriented and experimentation projects.* Implementation-oriented projects translate research findings into practice. Experimentation projects conduct experiments using existing methods.
6. *Review completed course and lab work, establish background.* This can be done using something like the Undergraduate Research Student Information Sheet (URSIS) presented in Fig. 2.
7. *Design research using existing skills and adding two or three new methods or techniques.*
8. *Include a literature review*. This provides training on use of research databases, conceptualizing keywords and synthesizing information.
9. *Present research at a poster session.* Undergraduate students who participated in a classroom poster session were more likely to present future research at conferences and symposia.
10. *Provide a path to graduate study.* Design projects around student interests and goals. Illustrate how a project might lead to a master's thesis or doctoral dissertation.

Many of these principles can be seen in examples of Riga Research Team undergraduate study projects. Each project was time-limited and concrete and included a range of analytical methods designed to utilize the students' existing skills while exposing them to new techniques. The projects used teams of two to three researchers, often with a senior peer as the team's informal leader. Finally, as the undergraduate researchers completed their semester, presented their research and moved on to other goals—including medical school, graduate school and jobs in industry—other students in the group were able to develop the work into master's level and doctoral level studies.

These projects provide a glimpse of the potential of thermal analysis in undergraduate research. As a broad-based analytical platform, thermal analysis projects can apply to students in chemistry, biology, physics, and engineering. They can be adapted for pre-medical, pre-dental, and pre-pharmacy students working side-by-side in the same lab space. And that mixture of interests, knowledge, goals, and disciplines sets the stage for some high-energy reactions.

References

1. Terrell N. Science technology engineering mathematics occupations. Occup Outlook Q. 2007;51(1):26–33.
2. Tanaka H, Koga N. Thermal analysis and kinetics of solid-state reactions: its application to education in chemistry. J Therm Anal Calorim. 1999;56:855–61.
3. Hakvoort G, Hakvoort TE. A practical thermal analysis course. J Therm Anal Calorim. 1997;49:1715–23.
4. Riga A, Bracone N, O'Connor A, Somrack A, Oberoi L, Alexander K. Thermal analysis in university research and undergraduate teaching labs. In: Proceedings of 32nd NATAS conference; 2004. p. 104.
5. Wunderlich B. Teaching thermal analysis of polymeric materials. J Therm Anal Calorim. 2000;59:7–19.
6. Sørensen OT. A new dimension in thermal analysis: virtual classroom teaching over the Internet. J Therm Anal Calorim. 2005;80:793–4.
7. Boyer Commission on Educating Undergraduates in the Research University. Reinventing undergraduate education: a blueprint for America's research universities. Stony Brook: State University of New York at Stony Brook for the Carnegie Foundation for the Advancement of Teaching; 1998.
8. Suga H. Prospects of materials science: from crystalline to amorphous solids. J Therm Anal Calorim. 2000;60:957–74.
9. Short N, Riga AT, Dutra de Souza KC, Alexander KS. Thermal and analytical characterization of a polymorphic drug: nifedipine. In: Proceedings of 33rd NATAS conference; 2005. disk paper.
10. Zaboura D, Riga AT, Short N, Dutra de Souza KC, Alexander KS. Thermal and analytical characterization of a polymorphic drug: tolbutamide. In: Proceedings of 33rd NATAS conference; 2005. disk paper.
11. Najjar O, Matthews ME, Presswala L, Atkinson I, Gerhardstein N, Moran J, Wei R, Riga AT. Essential physical-chemical properties of D and L amino acids by thermal and analytical methods. Podium Presentation, American Chemical Society Meeting-in-Miniature, Notre Dame College, South Euclid, Ohio; 2007.
12. Maheswaram MPK, Riga A, Alexander K. (2009). An innovative dielectric method determined the crystalline and amorphous content in pharmaceuticals. Poster, College of Science Research Day 2009, Cleveland State University, Cleveland, Ohio. http://www.csuohio.edu/sciences/researchday/2009/abstracts09.pdf.
13. Seymour E, Hunter A-B, Laursen SL, DeAntoni T. Establishing the benefits of research experiences for undergraduates in the sciences: first findings from a three-year study. Sci Educ. 2004;88(4):493–534.
14. Adhikari N, Nolan D. "But what good came of it at last?": how to assess the value of undergraduate research. Not AMS. 2002; 49(10):1252–7.
15. Barlow A, Villarejo M. Making a difference for minorities: evaluation of an education enrichment program. J Res Sci Teach. 2004;41(9):861–81.
16. Gordon EW, Bridglall BL. Creating excellence and increasing ethnic minority leadership in science, engineering, mathematics and technology: a study of the Meyerhoff Scholars Program at the University of Maryland-Baltimore County; 2004. Retrieved April 15, 2010 from http://www.ncrel.org/gap/studies/meyerhoff.pdf.
17. Hathaway R, Nagda B, Gregerman S. The relationship of undergraduate research participation to graduate and professional educational pursuit: an empirical study. J Coll Stud Dev. 2002;43(5):614–31.
18. Hunter AB, Laursen SA, Seymour E. Becoming a scientist: the role of undergraduate research in students' cognitive, personal and professional development. Sci Educ. 2006;91:36–74.

19. Kremer JF, Bringle RG. The effects of intensive research experience on the careers of talented undergraduates. J Res Dev Educ. 1990;24(1):1–5.
20. Lopatto D. Undergraduate research experiences support science career decisions and active learning. CBE Life Sci Educ. 2007;6(4):297–305.
21. Russell SH, Hancock MP, McCullogh J. The pipeline: benefits of undergraduate research experiences. Science. 2007;316:548–9.
22. Wenderholm E. Challenges and the elements of success in undergraduate research. SIGSCE Bull. 2004;36(4):73–5.
23. Bauer KW, Bennett JS. Alumni perceptions used to assess undergraduate research experience. J Higher Educ. 2003;74(2): 210–30.
24. Lopatto D. The essential features of undergraduate research. CUR Q. 2003;23:139–42.
25. Lopatto D. Survey of Undergraduate Research Experiences (SURE): first findings. Cell Biol Educ. 2004;3:270–7.
26. Mabrouk P, Peters K. Student perspectives on undergraduate research experiences in chemistry and biology. CUR Q. 2000;21:25–33.
27. Mervis J. Student research: what is it good for? Science. 2001;293:1614–5.
28. Nagda BA, Gregerman SR, Jonides J, von Hippel W, Lerner JS. Undergraduate student-faculty research partnerships affect student retention. Rev High Educ. 1998;22(1):55–72.
29. Pearson M, Brew A. Research training and supervision development. Stud High Educ. 2002;27:135–50.
30. Russell SH. Evaluation of NSF support for undergraduate research opportunities: 2003 NSF program participant survey (Draft Final Report to the NSF). Menlo Park, CA: SRI International. 2005. Retrieved April 15, 2010 from http://www.sri/com/policy/csted/reports/.
31. Summers MF, Hrabowski FA. Preparing minority scientists and engineers. Science. 2006;311:1870–1.
32. Tang BL, Gan YH. Preparing the senior or graduating student for graduate research. Biochem Mol Biol Educ. 2005;33:277–80.
33. Tomovic MM. Undergraduate research—prerequisite for successful lifelong learning. ASEE Conf Proc. 1994;1:1469–70.
34. Ward C, Bennett J, Bauer K. Content analysis of undergraduate research student evaluations. 2002. Retrieved April 15, 2010 from http://www.udel.edu/RARE.
35. Zydney A, Bennett JS, Shahid A, Bauer K. Impact of undergraduate research experience in engineering. J Eng Educ. 2002;19(2):151–7.
36. Zydney A, Bennett JS, Shahid A, Bauer K. Faculty perspectives regarding the undergraduate research experience in science and engineering. J Eng Educ. 2002;19(3):291–7.