Expository Programs: An Effective Approach to Enhance K-12 Engineering Education

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Abstract - **The expository model is an inquiry-based science program that enhances K-12 and the public understanding of science and technology through interactive demonstrations and hands-on experiences. The expository programs consist of a nucleus of graduate and undergraduate students (fellows) with the goal of enhancing the understanding of science and technology of K-12 teachers and students. Three sub-programs form this relationship: Science on Wheels (SONW) that uses demonstrations to communicate the world of chemistry, Global Learning and Observations to Benefit the Environment (GLOBE) that helps integrating environmental science into schools, and Calculator Based Laboratory (CBL), which uses probes to incorporate chemistry and mathematics into the curriculum. The chemistry demonstrations have contributed to spark the interest in science to more than 71, 900 individuals, while 85 fellows contributed to the education of 18,154 students and 372 teachers by means of GLOBE and CBL. Thus, data in the last years indicated that the number of students enrolled in science departments representing 90 high schools participating in the GK-12 projects increased significantly in science and engineering. The results suggests that those students interacting with GK-12 fellows are motivated to learn more and may obtain schools grades, which can facilitating their entrance to the university.**

Index Terms - Expository based model, hands on experiences, science and engineering education and science literacy.

INTRODUCTION

Our modern and technological world has been shaped by the work of many illustrious scientists emerging from divergent frontiers and cultures across the history of humankind. Because these scientists have changed the construct of human society from multiple, yet eventually unified perspectives, a brief synopsis of their work illustrates the importance of attaining the public's understanding, support, and appreciation for science and technology through science literacy programs. The nonlinearity of these changes can be initiated with Empedocles of Greece, (V B. C.), who suggested that the fundamental nature of matter was air, water, fire, and soil. Almost 2000 years latter, this idea changed during the period of R. Boyle (1627-1691) and A. Lavoisier (1743-1794) where the character of gases and the elementary decomposition of water into oxygen and hydrogen were demonstrated. In the turnover of the next two centuries (XIX and XX), humankind changed forever with the atomic theory of matter by characters like E. Rutherford (1871-1937), N. Bohr (1885 -1962), M. Planck (1858-1947), E. Schrödinger (1887-1961), L. De Broglie (1892- 1987), and W. Heisenberg (1901-1976). These scientists with the interface of other generations represented by L. Pauling (1901-1994), the visualization of the chemical bond, the DNA structure, and the substitution of the slide rule by the computer, lead the exploration of nanotechnology, biotechnology, ultra-short atosecond time regimes, and the communications world that we are today. As indicated earlier, these scientific advances should inspire the design of science literacy programs with the primary goal of improving the public's knowledge, support, and appreciation for the development and preservation of science and technology.

One approach to enhance the understanding of science and technology is focusing considerable efforts into K-12 education. The purpose of such an educational initiative should be twofold: (1) increase and improve the learning of the students in science, technology, and mathematics and (2) generate a strong public support for science literacy through teachers and parents, the industry, and the government. To envision that K-12 students with knowledge in science, technology, and mathematics will be able to build a strong foundation to further foster the development of our society is important [1], [7], [15]. Conversely, in-service and pre-service teachers with knowledge in science engineering and teaching are critical for the success of these students [10]-[12], [14], [16], [17], [19].

There are a number of nationwide outreach programs, educational articles, books and manuscripts describing hands-on science activities and learning opportunities for K-12 students and teachers [4], [6], [8], [9], [20], [22]. One effective outreach approach is the expository model-based science program. The expository model is an inquiry-based science program that enhances K-12 and the public understanding of science and technology through interactive demonstrations and hands-on experiences.

The expository model-based science programs discussed in this paper utilizes university graduate and undergraduate students that coherently link K-12 teachers and the public to improve mathematics, science and technology. For example, our knowledge base suggests that SONW, GLOBE, and CBL are all expository science programs that enhance the understanding and experimental skills of participants in ways that increase the number of college-bound students accepted to major in science and engineering. Moreover, the mentoring of K-12 students through expository model-based science programs is a crucial step in the direction of scientific literacy and technology.

STRATEGY AND THEME OF THE EXPOSITORY PROGRAM

The idea to empower university graduate and undergraduate students in science and technology through an expository program can be a vital solution to present and future links between scientific literacy and K-12 education. However, previously to any serious expansion of these programs it is necessary to evaluate these critical questions: Can expository science programs enhance K-12 education? Can expository programs increase the motivation and basic knowledge needed by high schools students to pursue undergraduate education? Can university science and engineering students be a driving force helping to improve the understanding of science? Can expository programs improve the public understanding of science? To answer these questions, we will use as model the number of students that has been accepted to major in science and engineering at the University of Puerto Rico, Mayagüez Campus (UPRM). The students came from 90 high schools, which have been interacting with the program, from 414 high schools in the survey. Figure 1 shows the hierarchical components of the expository program from the Science on Wheels Educational Center, located at Chemistry Department at UPRM.

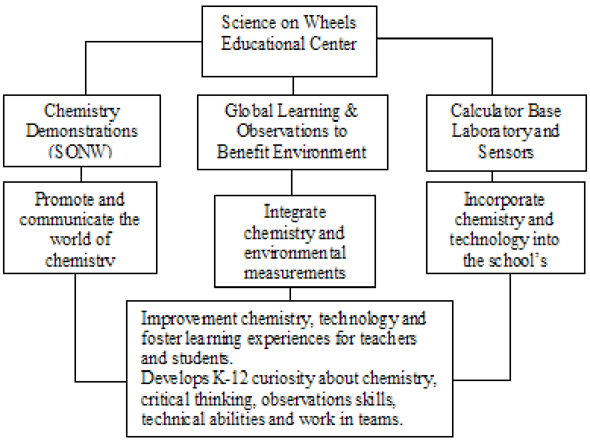

FIGURE I
HIERARCHICAL COMPONENTS OF THE EXPOSITORY PROGRAMS

The UPRM Campus has nearly 13,000 Hispanic students and offers sixteen different bachelor's (BS) and master's of science (MS) degrees in the colleges of Engineering, Arts and Sciences, Business Administration, and Agriculture. In addition, it offers Ph.D. programs in Applied Chemistry, Chemical and Civil Engineering, Marine Science, and Computational Mathematics. Three sub-programs provide the pedagogical framework for the demonstrations and the hands-on experiences of K-12 teachers and students. Firstly, Science on Wheels (SONW, http://sonw.uprm.edu) that uses demonstrations to promote and communicate the world of chemistry to teachers, students, and the public [9]. Secondly, Global Learning and Observations to Benefit the Environment, (GLOBE, www.GLOBE.gov) that helps integrate chemistry and environmental measurements into the schools curriculum and experimental discovery [1], [2]. Thirdly, the Calculator Based Laboratory (CBL) which uses graphic calculator and sensors to incorporate mathematics, chemistry, and technology to further foster inquiry-based, hands-on learning experiences [3].

The expository program first sparks the imagination through chemistry demonstrations and then uses GLOBE and CBL activities as platforms to helping teachers in chemistry. From 1991 to 2006, 130 fellows (84 undergraduate and 46 graduate students) presented 285 science shows to more than 74,500 persons (teachers, students and the general public) giving them the opportunity to boost their interest for chemistry. This opportunity also allowed a statistical approach to evaluate the students' preference to study a particular discipline as illustrated by Figure II.

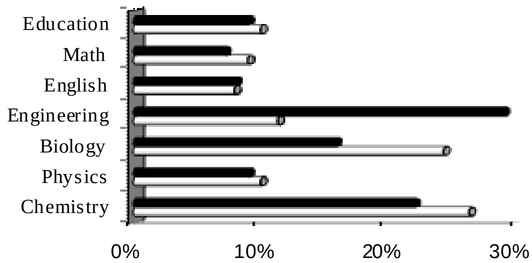

FIGURE II
PREFFERED STUDY AREAS

For example, based on the 15% of the students present in the activities, 10% of the male and female population had preference to study physics, mathematics, education, and the English language. The highest preference for male students was engineering (30%), followed by chemistry (22%) and biology (15%), whereas the highest choice for female students was chemistry (26%), followed by biology (25%) and engineering (17%). In agreement with previous studies, these evaluations show that 90 % of participants indicated that demonstrations are successful in generating interest for chemistry [1], [9]. Thus, the expository program approach helps to enhance the perception of science and technology to broad audiences. However, recognizing the influence of K-12 teachers in their students, a comprehensive schools-university approach has been established which includes: (1) Summer workshops, (2) Saturday academies, and (3) follow-up activities including visits to schools and the university. These activities have helped the enhancement of chemistry and environmental concepts in teachers and students. The GLOBE program can also be used to learn basic principles of chemistry and the environment. For example, through the atmospheric protocol, teachers and students learn concepts and experimentally determine: (1) the volume per day of rainwater, (2) the rainwater's pH, (3) the maximum and minimum temperatures, and (4) the ozone in the air. In the hydrology protocol, they measure: (1) temperature, (2) dissolved oxygen, (3) pH, (4) conductivity, (5) salinity, (6) alkalinity, and (7) nitrates concentration present in lakes, rivers, and streams. A further development of skills is achieved when data are obtained using CBL coupled to probes. These units are portable hand-held devices and thus fellows bring the instrumentation into the classrooms, allowing all the students to have integrated experimental experiences. The measurements promote the integration of chemistry concepts, cooperative learning activities, and inquiry experiences to teachers and their students. In this regard, a core of graduate and undergraduate students, under the NSF Graduate Teaching Fellows in K-12 Education (GK-12), provided education and training. The fellows present detailed explanations and experiments related of the curricular topic under discussion. Their preparation and experience help them transfer research ideas into pre-college environments enhancing also K-12 teachers' knowledge and understanding of chemistry principles. Simultaneously, teachers provide first-hand experiences to fellows as effective classroom communicators and help them develop the appropriate language and skills for the K-12 environment. In this way, the expository program: (1) implements a cost-effective program reaching teachers and students, (2) continues teachers' professional development, (3) involves students in educational initiatives helping them in chemistry concepts and experimental measurements, (4) motivates students to register in chemistry courses while participating in science programs, (5) improves the scientific background and understanding of high school students, and (6) increases community awareness by involving parents in sample and data collection.

EDUCATION AND TRAINING OF THE PARTICIPANTS

Selection of the Fellows and Teachers

The graduate and undergraduate fellows participating in the programs are selected from UPRM students pursuing degrees in science (i.e. chemistry, biology, geology, mathematics, agronomy) and engineering (i.e. chemical. mechanical, electrical). University professors form a committee that evaluates the applicants using the following criteria: (1) acceptable grade point average, (2) written and oral communication skills, (3) teaching and outreach experiences, (4) willingness to work with K-12 teachers and students, and (5) experimental abilities. The applicants are required to submit an essay describing their vision on K-12 education, which must include the impact that they could produce in the teachers and students because of their interactions. About 25% of the applicants are selected to participate in the program. Once selected, fellows are required to complete 15 hours/week of informal (interactions and visits to schools and teachers) and formal training (course work, research, and sessions with individual investigators) during this period. Every year and a half, the fellows are substituted by a new group of university students. One the other hand, about 30% of the teachers is selected to the program and most undergo formal summer training.

Fellows and teachers training in GLOBE and CBL

The educational processes begin when a core of professors provide the appropriate science, technology, and learning activities to the fellows improving their capabilities to interact with K-12 teachers and students through inquiry-based science and technology demonstrations as well as hands-on experiences. The formal teachers' training occurs during summer weeklong workshops, which may be focused on GLOBE protocols or CBL activities in chemistry. It is important to realize that these are two sequential programs. First, teachers and fellows are trained in the chemistry and environmental concepts and measurement of GLOBE program following the strategy and procedures described in an early manuscript [1]. Then, only those teachers that during two academic years have been continuously integrating GLOBE activities into their classroom are invited to participate in the CBL and sensors workshops. During workshops, fellows and teachers learn how to use CBL and probes to obtain and analyze chemical data that were previously obtained using the technology established in the particular GLOBE protocols. For instance, the use of CBL and pH in soil, atmosphere, and hydrology protocols ties the pH definition to the concepts of acids and bases. This is also related to the measurements of the difference in pH in the waters from the sea, river, and rain. Similarly, the inverse relationship between dissolved oxygen and salinity is also explored establishing empirical discussions between fellows, teachers, and students. However, teacher workshops must have follow-up activities to boost their professional development, their confidence, as well as the skills needed to integrate into the classroom the learned concepts and experiments. Continuous meetings and visits to the schools by the fellows, reinforces the learning activities allowing teachers to enhance and discuss with their students the learned concepts and experiences. The visits also help maintaining strong links between fellows, teachers, and students, thus enhancing their perspectives about higher education.

IMPACT OF THE EXPOSITORY PROGRAMS

Although graduate and undergraduate students are the driving force of the program interactions, guidance from mentoring university professors provides additional support as fellows continue toward their own research and academic accomplishments. Therefore, is essential to evaluate the impact of the expository programs on the development of fellows, teachers, and students.

Evaluation of Fellows

To assess the fellows' perspectives of the program, they completed a Linker scale questionnaire with four choices going from very strong to very weak. Our data show that expository programs: (1) provide a mechanism that develops K-12 students' curiosity about chemistry (44% very strong, 38% strong), (2) help students to become more aware of the importance of chemistry in daily decisions (55% very strong, 22% strong), (3) provide new opportunities to integrate chemistry concepts into K-12 curricula (50% very strong, 22% strong), (4) 70% of the fellows sense that the program develops a better prepared core of school teachers and students becoming part of day to day education, and (5) more than 89% of the fellows feel, similar to a recent report [14], that chemistry and outreach programs need more attention and involvement of K-12 and higher education organizations. Fellows were also asked about personal benefits derived from their participation in the programs. The analysis indicated that fellows (a) developed self-confidence in teaching strategies and communication skills (50% very strong, 44% strong), (b) created alternative ways to communicate chemistry phenomena to K-12 students, teachers and the general public (61% very strong, 33% strong), (c) improved chemistry knowledge and experiences (44% very strong, 50% strong), and (d) simplified their preparation for seminars and interviewing (61% very strong, 22% strong). For the fellows, these experiences prepare them to examine critically the effectiveness of teaching methods and approaches in their own scientific careers. The perspectives strongly indicate that coherent interactions between university fellows and schools certainly enhance science and technology education.

Workshops, schools visits, and follow-up activities

Sometimes, schools from rural areas and towns have limited resources or little access to hands-on experiences in chemistry and technology education. A peculiarity of this environment is also that a relatively high percentage of chemistry teachers do not have a bachelor's degree in chemistry or in related science fields. Table I shows that from 2001 to 2006, 108 fellows (94 graduate and 14 undergraduate students) lead the training of 404 teachers by means of 15 workshops and 63 Saturday follow-up activities. The result has been 1,151 direct visits, from one to three contact hours with 20,116 school students, helping them to learn chemistry concepts and obtain experimental measurements of chemical and environmental processes.

TABLE I
NUMBER OF THE PARTICIPANTS AND ACTIVITIES IN THE GK-12 PROGRAM

Year	University Fellows	Training & Follow-up Workshops	Teachers Trained	Schools Visits	Students Trained
2001	20 (18,2)	2,5	39	159	3201
2002	20 (18,2)	3,13	82	229	3107
2003	20 (18,2)	3,9	77	315	5575
2004	12 (10,2)	4,18	115	161	2484
2005	13 (11,2)	2,9	59	177	3787
2006	13 (11,2)	1,5	32	80	1,562
2007	10(8,2)	0,4	0	30	400
Total	**108 (94,14)**	**15 , 63**	**404**	**1,151**	**20,116**

Thus, the GLOBE and CBL workshops provided teachers with a complementary background in science, chemistry, environment, and mathematics, as well as with much needed ideas for curriculum improvement and inquiry. In these programs, the participation of the fellows as role models and facilitators is fundamental in fostering self-directed development in schools students. The increase in the number of fellows, mainly supported by the NSF GK-12 program, shows a correlation with the number of such activities as workshops, follow-up visits, and Saturday academies.

Quantitative impact of the Expository Program

The data for the evaluation of the expository program were obtained from the Office of Institutional Research and Planning of the University of Puerto Rico, Mayagüez Campus, which allowed a quantitative determination of the number of students entering the university to study science and engineering. In particular, Figure III shows the ratio of the number students per schools entering to study a bachelor's degree in science (biology, chemistry, agronomy, geology, biotechnology, and physics) from the 414 high schools in Puerto Rico during the years 2001 to 2005. For example, in the year 2001, the 158/324 ratio (white area) represents 158 students accepted to study a BS in science from the 324 schools not visited by the program, while the 62/90 ratio (solid area) represents 62 students that were accepted from 90 schools belonging to the program.

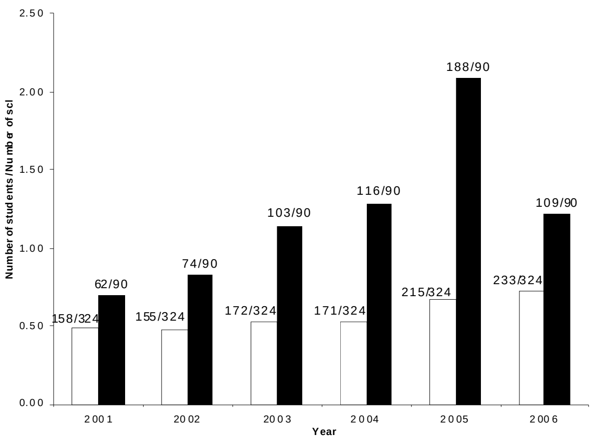

FIGURE III
NUMBER OF STUDENTS ENTERING THE UNIVERSITY TO STUDYSCIENCE FROM 324 NON-VISITED AND 90 VISITED SCHOOLS

The results show an exponential increase in the number of students that entered the university form the schools impacted by the expository program. Thus, from 2001 to 2006 there was an increase in the number of students from the participating schools, while through these years the number of students from the not visited schools remained almost constant. Similarly, Figure IV shows the ratio of the number students per schools that entered to study a bachelor's degree in engineering (chemical, electrical, civil, mechanical, and computer) from the 414 high schools in Puerto Rico. For example, in the year 2001, the 554/324 ratio (white area) represents 554 students accepted to study a BS in Engineering from the 324 schools not visited by the program, while the 250/90 ratio (solid area) shows that 204 students were accepted from 250 schools belonging to the expository program.

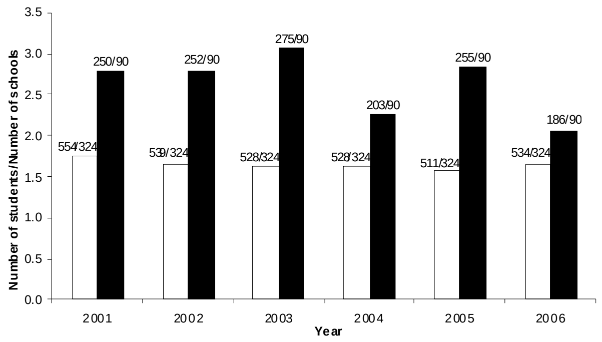

FIGURE IV.
NUMBER OF STUDENTS ENTERING THE UNIVERSITY TO STUDY ENGINEERING FROM 324 NON-VISITED AND 90 VISITED SCHOOLS.

As seen, the number of students that entered the university from the schools impacted by the expository program was constantly higher that the number of students coming from not-visited schools. In Figure V, a similar pattern in the students that study Chemical Engineering is observed. Thus, an increase of interactions between teachers and fellows yields consequently, a significant increase in the number of high school students admitted to the engineering department.

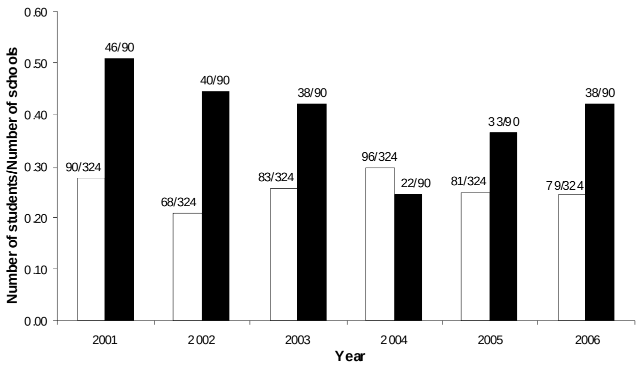

FIGURE V
NUMBER OF STUDENTS ENTERING THE UNIVERSITY TO STUDY CHEMICAL ENGINEERING FROM 324 NON-VISITED AND 90 VISITED SCHOOLS.

CONCLUSIONS

An assessment of the expository programs described herein suggests that access to hands-on experiences in science, math, and technology, enhances K-12 education and public science education. The participation of university fellows as role models and facilitators is critical for curriculum improvement and the development of inquiry-based science skills in K-12 teachers and students. The expository programs enhance motivation while building the knowledge base required by college bound students interested in pursuing science and engineering careers. Finally, the university and K-12 partnership promotes the public understanding of science and technology as indicated by an increase in the number of students majoring in science and engineering.

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REFERENCES

[1] Camacho, R., López-Garriga, J. Integration of Pre-college Chemistry Education and the GLOBE (Global Learning and Observations to Benefit the Environment) Program. *Journal of Chemical Education*, 77, 2000, 1586-1539.

[2] Coppola, R.K. and Butler, D.M, eds., GLOBE Program Teacher's Guide, *The GLOBE Program and National Atmospheric and Oceanic Administration*, 1997.

[3] Cortés-Figueroa, J. E., Moore, D. A., Schuman, M. J. Using a CBL Unit, a Temperature Sensor, and a Graphing Calculator To Model the Kinetics of Consecutive First-Order Reactions as Safe In- Class Demonstrations. *Journal of Chemical Education*, 83, 2006, 64-68.

[4] DeClue, M.E., Johnson, K., Hendrickson, H., Keck, P.). Stimulate High School Science Fair Participation by Connecting with a Nearby College. *Journal of Chemical Education*, 77, 2000, 608-609.

[5] Eckenrode, H. M., Gifford, L. K., Rogers, L. C. A Partnership Incorporating Labs into an Existing Chemistry Curriculum: Access Science. *Journal of Chemical Education*, 81, 2004, 505-1509.

[6] Exstrom, C. L., Mosher, M.D. A Novel High School Chemistry Camp as an Outreach Model for Regional Colleges and Universities. *Journal of Chemical Education*, 77, 2000, 1295-1297.

[7] Flynn, N. Science Days: An Interdisciplinary Outreach Program. *Journal of Chemical Education*, 82, 2005, 1483-1485.

[8] Hapkiewicz, A. Authentic Research within the Grasp of High School Students. *Journal of Chemical Education*, 76, 1999, 1212-1215.

[9] López-Garriga, J., Muñoz, Y., Torres, V., Echevarria, Y., Nazario, W., De Jesus, W., Camacho-Zapata, R.. Science on Wheels: A Coherent Link Between Educational Perspectives. *Journal of Chemical Education*, 74, 1997, 1346-1349.

[10] Mahaffy, P. Chemists' Understanding of the Public. *Chemistry International*, 28(4),2006, 14.

[11] Tai, R. H., Qi Liu C., Xitao Fan, M. (2006). Planning Early for Careers in Science. *Science*, 2006, 313, 1143-1144.

[12] National Science Board report on "Preparing our Children: Math and Science Education in the National Interests", 1999.

[13] National Science Board report on "The Science and Engineering Workforce Realizing America's Potential", 2003.

[14] National Science Board report on "America's Pressing Challenge-Building a Stronger Foundation", 2006.

[15] Nozawa, F., Meyer, L. S., Nozawa, F., Panee, D., Kisler, M. Using Demonstrations to Promote Student Comprehension in Chemistry. *Journal of Chemical Education*, 80, 2003, 431-435.

[16] Otero, V. Finkelstein, N., McCray, R., Pollock, S. Who Is Responsible for Preparing Science Teachers? *Science*, 313, 2006, 445-446.

[17] Pfund, C., Pribbenow, C. M., Branchaw, J., Lauffer, S. M., Handelsman, Jo. The Merits of Training Mentors. *Science*, 311, 2006, 473-474.

[18] Phillips, D. B. CHEM 101: Thirty Years of Experiences with a Chemistry Course for Prospective Elementary School Teachers. *Journal of Chemical Education*, 78, 2001, 905-907.

[19] Runquist, O., Kerr S. Are We Serious about Preparing Chemists for the 21st Century Workplace or Are We Just Teaching Chemistry? *Journal of Chemical Education*, 82, 2005, 231-233.

[20] Shakahashiri, B. *Chemical Demonstrations: A Handbook for Teachers of Chemistry;* The University of Wisconsin Press: Madison, Wisconsin. 1989; Vol. 1-4.

[21] Stout, R.. The Chemicals Project": Connecting General Chemistry to Students' Lives. *Journal of Chemical Education*, 77, 2000, 1301-1302.

[22] Towns M. H. How Do I Get My Students to Work Together? Getting Cooperative Learning Started. *Journal of Chemical Education*, *75*, 1998, 67-69.