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Teaching Content, Context, Collaboration, and Communication in College Chemistry

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Introduction

The pace of the expansion of the frontiers of science is increasing and this poses an ever more pressing problem for science education. The gap between the way students are taught and how students might employ scientific knowledge has become nearly unbreachable. The overwhelming majority of students are taught chemistry concepts in isolation from the scientific process and the concepts' actual applications. In its 1996 report *Shaping the Future—New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology (STEM)* [1], the National Science Foundation of the United States (NSF) recommended that faculty “*model good practices that increase learning; start with the student’s experience, but have high expectations with a supportive climate; and build inquiry, a sense of wonder and the excitement of discovery, plus communication and teamwork, critical thinking, and lifelong learning skills into learning experiences.*” This policy is aligned with a century of general education policy [2] and the policy addresses a fundamental pillar for a democratic society, the need for a literate citizenry [3]. Thomas Jefferson famously wrote in 1787, that “*the basis of our governments being the opinion of the people, the very first object should be to keep that right; and were it left to me to decide whether we should have a government without newspapers or newspapers without a government, I should not hesitate a moment to prefer the latter. But I should mean that every man should receive those papers and be capable of reading them* [emphasis ours].” In today’s modern society, literacy increasingly means *scientific* literacy [4-6] and Jefferson’s mandate requires science literacy, a basic appreciation for the science process by the general public [4], and also the public engagement by scientists [7].

Chemistry Is in The News (CIITN) has been developed over the past fifteen years with the aim of teaching chemistry in the context of real-world issues and exposing students to all aspects of

science communication. The pedagogical framework [8-10] and technical issues [11] of implementation have been described and reviewed [12-14], and results of assessment [15,16] have been reported. The *CIITN* activities consist in the study, creation, and peer review of online projects that are based on actual news articles from the popular press and aimed at connecting real-world social, economic, and political issues to the teaching of chemistry. *CIITN* is based on constructivist learning theory [17], which holds that connecting abstract scientific concepts with real-world experience can help students learn and remember content. The *CIITN* peer review includes an evaluation framework for both individual and group evaluations, detailed and flexible rubrics to guide peer review, a requirement of written justifications of the peer review scores, and an intragroup peer review tool. *CIITN* was developed for lower-division, large lecture college courses and *CIITN* also has been implemented in high schools in the United States.

Here, we describe our more recent curriculum innovation [18], which embraces the spirit and expands on the concepts of *CIITN* to educate upper-level science majors about the science process, scientific writing, scientific peer review, and professional issues. Specifically, we describe the framework of an assignment-based curriculum of a writing-intensive, upper-level undergraduate seminar taught at the University of Missouri in Columbia (MU), which integrates content, context, collaboration, and communication in a unique fashion. The topic of the seminar is “Scientific Writing in Chemistry” and an assignment-based curriculum was developed to instruct students on best practices on all aspects of science communication and to educate students about the scientific publication process and peer review. To effectively teach students how to understand science, one must include both the content and the process and peer review is an

integral and essential part of the process of science. The curriculum was developed for a semester-long, three-hour seminar course with limited enrolment (< 36 students). The curriculum was taught in the spring semesters of 2010 – 2013 and results of assessments are presented to demonstrate the success of the adaptation.

The educational goals of education in science communication are strongly connected to the general education goals of writing programs. For example, the premise of MU's Campus Writing Program [19] states that "*Writing Intensive courses help produce an educated, articulate citizenry capable of reasoning critically, solving complex problems, and communicating with clear and effective language.*" It's a simple equation: *Scientific Writing & Communication = Science Content + Writing-Intensive Principles*. This natural alignment between science communication and writing programs can be an effective catalyst for the initiation of science communication programs in science departments. We have been working closely with the Campus Writing Program (CWP) on the *CIITN* curriculum, and we have been developing the "Scientific Writing in Chemistry" curriculum with continuing support from CWP and many WI-faculty from a variety of disciplines. The assignment-based curriculum meets CWP's criteria for writing-intensive courses, and the curriculum was reviewed and approved by an interdisciplinary group of faculty peers prior to each implementation.

While the curriculum has been developed for students at an American research university, the *framework* of the assignment-based approach is *entirely transferable to other sciences and other educational levels*. Most science departments do not offer formalized courses to teach science process skills at the undergraduate level and/or to beginning graduate students. Evidence suggests that the teaching of process skills at the undergraduate level can enhance the students' understanding of science content [20], and prepare them for the increasingly interdisciplinary and collaborative nature of the modern scientific enterprise [21,22]. To affect lasting and sustained growth in the understanding of the science process, however, these educational efforts should not be limited to the college and university levels. Instead, faculty at the college level ought to commit to improving the training of teachers and

to working with teachers on the implementation of more scientific approaches to science instruction [23]. The curriculum for the education in science writing and science communication is very much in the spirit of the Next Generation Science Standards [24,25] and its implications for college teaching [26]. While educational standards used to be formulated by professional organizations in the various subject areas, the next generation standards call for "fewer, clearer, and higher" and more integrated standards. The goals of literacy and STEM education should enable citizens to argue from evidence. To move education in that direction will require more attention to science process (problem definition, model formulation, data analysis) and draw on elements from science, mathematics and ELA ("literacy", English Language Arts). Thus, it is hoped that this article will contribute to the wide and open dissemination of this curriculum on science writing and science communication.

Framework of the Assignment-Based Curriculum and Organization of the Course

We describe a *framework* of an assignment-based curriculum. The *types* and *sequence* of the assignments and the *modes of their assessment by peer review* constitute this framework and remain essentially the same from one implementation to the next (Table 1). Every *implementation of this framework* presents a unique curriculum because all assignments are original and connected to an overarching theme of the course.

Our original implementation in the spring semester of 2010 (SP10) was built around the theme "Aspirin and Other Painkillers." In the following years the course was built around the themes "Dyes, Indicators, and Chemical Sensors" (SP11), "Soaps, Detergents, and Other Amphiphiles" (SP12), and "Solar Energy and Other Renewables" (SP13). As this article is being written, students are taking this course with the theme "Nutraceuticals: Sources, Delivery, and Functions" (SP14). All of these assignments, associated data and sources, peer review devices, and samples of completed assignments are available online and the URLs for the course web sites are provided as footnotes to Table 1. The *framework* of the curriculum has been developed with a few elemental criteria in mind and these are: Compartmentalization of Tasks, Incremental

and Iterative Progress, Clarity of Process and Requirements, and Clarity of Purpose.

Table 1. MU Course Design: Content, Software, and Resources

Week	Task	Content	Software and Online Resources
1		Reading Chemical Literature, Publication Types	Browser, Portals: ACS, Wiley-VCH, RSC
<i>Skill Development for Scientific Writing</i>			
2	A01	Mindmapping & Outlining, Text	Word
3	A02	Schemes; Integration of Text & Art	ChemDraw, Word
4	A03	Tables, Statistics & Graphing	Excel
5	A04	Simulation & Graphing	Excel, Word, ChemDraw,
6	A05	Search, Citation & Bibliography	SciFinder, Word, ChemDraw
7	A06	Oral Presentation	Powerpoint
8		Oral Presentation Week	
9	A07	Structure and Modeling	Chem3D, Jmol etc.
<i>Near-Authentic Exercise in Scientific Writing and Authoring</i>			
10	A08	Writing I. Materials, Methods, Appendix	<i>J. Org. Chem.</i> , Guidelines for Authors
11	A09	Writing II. Intro., R & D, Concl., Abs., Cover Letter	Authentic Examples provided
12	A10	Scientific Peer Review	Ethics Guidelines: ACS and NAS
13	A11	Revising & Responding to Peers, Graph. Abstract	Authentic Peer Review Examples provided
14		Scientific Conduct and Misconduct	PR-Cases & ORI-Resources

(a) In SP10, the oral presentation was "Project #1" and it became A06 in subsequent implementation. Hence, A06 – A10 in SP10 correspond to A07 – A11 of all subsequent implementations.

(b) Spring Semester 2010: http://faculty.missouri.edu/~glaserr/RG_T_SP10.html

(c) Spring Semester 2011: http://faculty.missouri.edu/~glaserr/RG_T_SP11.html.

(d) Spring Semester 2012: http://faculty.missouri.edu/~glaserr/RG_T_SP12.html.

(e) Spring Semester 2013: http://faculty.missouri.edu/~glaserr/RG_T_SP13.html.

(f) Spring Semester 2014: http://faculty.missouri.edu/~glaserr/RG_T_SP14.html.

Writing a paper is very hard! And writing a paper requires proficiency in many skills. One needs to learn how to find, access, and read literature, one needs to learn how to collect and work with data, how to create schemes and figures, and one needs to acquire computer skills to handle all kinds of software pieces needed to perform the desired tasks, and one must learn about the publication process and peer review. Evidence suggests [27,28] that it is best to compartmentalize these various tasks as much as possible and to gradually move from relatively simple tasks to more and more complex tasks, which build on previous assignments and require the integration of several skills. Hence, we dedicate more than half of the curriculum to modules for “Skill Development for Scientific Writing” (A01 – A07) and, with this preparation, the students then engage in a “Near-Authentic Exercise in Scientific Writing and Authoring” (A08 – A11, vide infra).

The incremental increase in the complexity of the tasks is reflected in the gradual increase in the students’ autonomy regarding their selections of topic and sources. In assignments A01 – A04, the students work on common topics and they select literature from a provided pool of sources about the theme area. In assignments A05 – A07, the students work on different topics and they select one topic from a provided pool of pre-selected topics within the theme area. Finally, in assignments A08 – A11, the students work on different topics they select freely from the primary literature covering the theme area, and a pool of journals is provided to facilitate their access to the primary literature of theme area.

All the activities in this course are performed by pairs of students. This stratagem has the imme-

diate organizational benefit that every group can stay on schedule in spite of the occasional absence by one of the collaborating students. Moreover, this stratagem also offers peer support [29] and several pedagogical advantages [30,31]. We have found that working in pairs greatly helps the students to manage the novelty of the course and to alleviate any doubts students might have as to whether they can live up to the challenges. Working on the assignments and on the peer reviews harvests the benefits of peer-to-peer learning [32,33] and especially promotes learning through collaborative argumentation [34].

The learning goals of the theme-based, research-oriented curriculum are well aligned with modern pedagogical principles. The framework of the curriculum emphasizes crosscutting concepts (structure & function, pattern recognition, cause & effect, etc.), informs about science practices, and provides instruction about all aspects of actual research. Table 2 shows how scientific writing correlates with the practices of science and engineering for the promotion of inquiry recommended by the National Research Council [35]. We encourage the selection of themes that are timely and relevant. Science affects every aspect of modern society and students need to learn to use employ their science knowledge when they recognize options and make choices mindful of the consequences. The MU Campus Writing Program suggests that assignments should be “unique, original, or specific to a task or problem” and provides specific recommendations to guide assignment design. Assignments that match these criteria also minimize any concerns about plagiarism [36].

Table 2. NRC’s Eight Practices of Inquiry in STEM Education and Scientific Writing

NRC’s Operational Criteria for Inquiry	Standard Science Sequence
(i) asking questions & defining problems	Introduction
(ii) developing & using models	All Sections
(iii) planning & carrying out investigations	Materials & Methods (M&M)
(iv) analyzing & interpreting data	Results & Discussion (R&D)
(v) using mathematics & computational thinking	R&D
(vi) constructing explanations & designing solutions	R&D
(vii) engaging in argument from evidence	Conclusion, R&D
(viii) obtaining, evaluating, & communicating information	All Sections

Evaluation of Assignments by Various Forms of Peer Review

The scholarly community has long had a love-hate relationship with peer review [37]. To a significant extent, the ill feelings toward peer review are a product of *viewing peer review simply as a practical tool for quality control* [38]. However, Knoll [38] argues that one should see peer review as a social process, that is, “*as a discussion among honest and able people, working within the social system of institutionalized science, making the clearest sense they can of the information they all share.*” It is this *discourse* that is the essence of science.

Most scientists have their first experience with peer review when they publish their first paper and *receive* peer review. For a working scientist, however, both *receiving* and *providing* peer reviews are regular activities, and students should develop the ability to deal with and benefit from received peer review and also the capacity to produce quality feedback on the works of others [39]. The assignment-based curriculum includes peer review activities that exercise both of these dimensions of peer review in a *gradually evolving fashion over the course of several months*. We hold that a thorough development of peer review skills is intrinsically connected to the development of writing skills: In the absence of well-developed writing skills and some experience in scientific writing, one cannot judge the creative works of others “as a peer.” Meaningful curricula for science writing and peer review thus can be connected to laboratory courses [40] or to lecture courses with significant [16] or intensive writing components.

Several forms of peer review are employed. The peer review tasks evolve from rubric-based peer assessments [41,42] to free format peer review. At the same time, the peer review tasks evolve from assessments of the writer’s technical and formal proficiencies and of the completeness of the assignment all the way to an evaluation of the writer’s capacities for excellence in topic selection, for logical organization and sequencing, for the logical construction of arguments and their clear presentation, and for sound judgments in the formulation of conclusions.

Rubric scoring is employed in the peer reviews of all of the assignments in the “Skill Development

for Scientific Writing” phase of the curriculum (A01 – A07). In this phase, each assignment usually is assessed by single peer review, and the peer review is managed to ensure that every group reviews another group only once. The oral presentations (A06) occur in three class meetings with 5 presentations per meeting. The presentations are assessed by rubric-based peer review by the students in the audience of a given session and excluding the students who present in the same session and the co-chairs of the session. With the rubric-based peer reviews given and received in A01 – A07, the students are well prepared for the “Near-Authentic Exercise in Scientific Writing and Authoring” and its three-fold, journal-style scientific peer review (*vide infra*).

Scientific Writing & Peer Review: Manuscript Preparation, Review and Revision

Science at its very core is “data-based, rational analysis” and the overwhelming majority of scientific papers contain original data. Aspects related to the acquisition of the original data are described in the “Materials and Methods” section and the original data are documented either in the paper or in an “Appendix” (Supporting Information). An authentic exercise in scientific writing must be concerned with the rational analysis of original data within the existing context. Yet, there are obvious limitations to original data generation in writing classes and the question is “How to write a scientific paper without original data?” To resolve this conundrum, we ask the students to identify a suitable topic in the theme area, to collect all relevant information about a recently described molecule/material (structure, preparation, chemical characterization, performance) and to “adopt these data as their own.” Hence, the students browse the recent primary literature in search of a subject of their choice, and a list of professional journals in the theme area is provided for initial guidance. Obviously, the students only *pretend* that the discovery of their “new” molecule/material is theirs. Each group is required to provide all sources about their molecule/material as a bibliography on the last page of the appendix of their paper. With this premise, assignments A08 – A11 constitute a contiguous sequence that creates a near-authentic experience in scientific writing and its assessment by scientific peer review.

The manuscript preparation requires a significant effort and the task is performed in two steps in assignments A08 and A09. Assignment A08 consists in the selection of the subject, the collection of all the required information, and the documentation of experimental methods and results in the materials and methods section and in the appendix of the projected paper. Assignment A08 is evaluated by rubric-based peer review to ensure that the groups are on track before they progress to the completion of their manuscripts in assignment A09. Assignment A09 builds on A08 and requires the writing of the sections Introduction, Results and Discussion, Conclusion, and Abstract. The students are required to compare the characteristic features of their “new” material to those of two other prominent materials with the same kind of function. This sort of comparison is very much a part of authentic research planning and reporting. With A09, the focus shifts from “reporting and documenting” to “analyzing, explaining, judging and concluding.” In addition, with A09 begins the instruction on the author’s publication correspondence and the students need to write a cover letter to accompany the submission of the paper.

Thus, everybody will write a paper on the general theme of the course and, at the same time, the papers will vary greatly because of the students’ original selections of their specific topics. It is this commonality of the general theme together with the variety of the specific topics that ensures competent peer review and, hence, assignments A10 and A11 truly provide instruction and practice in “scientific peer review.” Assignment 10 consists in the scientific peer review of A09 submissions. Every paper is peer reviewed by three groups following the peer review format and criteria of the *Journal of Organic Chemistry*. In assignment A11, the students respond to the peer reviews received. The students revise their manuscripts, write a rebuttal letter (i.e., a cover letter that describes and justifies all the changes made), and submit these items for a second round of peer reviews by the previous three referees. This review of the revised papers is a rubric-based peer review and the average score of three reviews becomes the A11 score.

Grading Scheme: Encourage High Quality Original Submissions

The grading scheme has evolved over the years. Initially, student course grades were based on their completion of all assignments in an

“acceptable manner.” With growing confidence in the quality and fairness of the peer review process, the grading scheme increasingly considered the peer review scores, and we describe the grading scheme implemented since the Spring Semester 2013.

The peer review of an assignment results in a peer review score (PRS) up to a maximum of PRS = 20. Various modes of revision are required depending on the peer review score of an original submission (PRSO). We value and reward high quality original submissions during the “*Skill Development for Scientific Writing*” phase of the course, and various types of revision are requested depending on the peer review score. No revision is required for a submission with PRSO ≥ 19 (“accepted as is”). More usually, the score falls in the range $19 > \text{PRSO} \geq 15$ (“minor revision required”) and the students are asked (a) to read the peer review comments carefully, (b) to revise their assignment considering the reviewer comments, and (c) to submit the revision in electronic form to the instructor with changes made with “tracking on.” The assignment is completed once the instructor accepts a satisfactory revision. Peer review scores PRSO < 15 (“major revision required”) happen rarely. In such an event, the students are asked to perform tasks (a) – (c) and the additional task (d): The submission of the revision needs to be accompanied by a description of the changes made and an explanation as to how these changes address the comments by the peer reviewers. The revision will be accepted once it scores above 15 points.

In the “*Near-Authentic Exercise in Scientific Writing and Authoring*” phase of the course, we again reward high quality original submissions of assignment A08, because all of the skills required for the execution of A08 have been acquired and practiced in A01 – A07. However, the original paper is scored only after scientific peer review and revision; i.e., A11 is scored while A09 is not scored.

Students are provided periodically with class performance measures (i.e., average, standard deviation, minimum and maximum scores) to assess their relative performance, and grades are assigned at the end of the course based on the student’s average of PRSO scores ($\langle \text{PRSO} \rangle$) as follows: “A” if $\langle \text{PRSO} \rangle \geq 19$, “A-” if $\langle \text{PRSO} \rangle \geq 18$, “B+” if $\langle \text{PRSO} \rangle \geq 17$, “B” if $\langle \text{PRSO} \rangle \geq 16$, “B-” if $\langle \text{PRSO} \rangle \geq 15$, and so on. In addition,

students can improve their grades by provision of exemplary work (which will be posted as sample, seven opportunities) and by delivery of an outstanding oral presentation (top three presentations) and/or submission of an outstanding final paper (top three papers). Every instance of a special recognition improves the grade by one notch. For example, a student with an average original peer review score of 17.5 and one submission selected for posting as a sample will receive an “A”.

Results of Assessment

Informal Assessments. Toward the end of the course, the students were asked to list the ten most pertinent keywords they associate with the course. The frequency analysis of the collected keywords provided a “wordle” of the type shown in Figure 1, where the font size of each word reflects its frequency. “Writing,” “Research,” and “Chemistry” usually are the top three association, and their relative frequencies vary from semester to semester. The fourth most frequent word usually has to do with the theme of the course (i.e., “Detergent” in SP12).

This outcome of the free association exercise is nicely aligned with the intended learning goals. The course educates in scientific writing in chemistry and it is research intensive. The themes of the courses facilitate these educational goals, and the themes are chosen to be sufficiently interesting and appealing to a general audience so

that chemistry content issues do not dominate the discourse. It also is noteworthy that some words occur only with low frequencies, and words associated with peer review fall into this category. Peer review was not a source of apprehension and, instead, the students were comfortable with the peer review process.

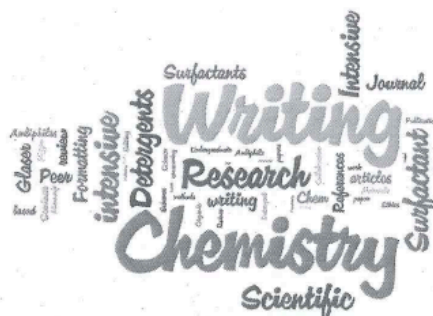


Figure 1. Wordle of the top-10 associations by the SP12 student at the end of the seminar course.

Formal Assessment. The students of all courses offered by MU’s Department of Chemistry are asked to rate the course and the teacher on the seven criteria listed in Table 3 using a five-level Likert scale (0 – 4, 4 is high). The “overall rating” is determined as the average of the numerical scores of the seven department questions, and this aggregate score is commonly used to measure teaching performance. The second part of the questionnaire asks the students to provide written answers to six questions and these are: 1. List the strong and weak features of the lecturer and

Table 3. Student Teaching Evaluations, Spring Semesters 2010 to 2013

#	Criteria of Evaluation	SP10 ^a	SP11 ^b	SP12 ^c	SP13 ^d
1	Organization and preparation of lectures and discussions	3.73	3.61	3.90	3.84
2	Instructor’s enthusiasm for the subject matter	3.96	3.96	4.00	3.96
3	Helpfulness in answering questions and clarifying points	3.50	3.35	3.76	3.84
4	Ability to lecture in a manner which is easily followed	3.46	3.52	3.76	3.72
5	Ability to stimulate interest in the subject	3.07	3.22	2.97	3.72
6	Overall rating of the instructor	3.69	3.57	3.66	3.88
7	Your rating of how much you have learned	3.34	3.26	3.34	3.66
8	Overall rating, Average of Questions 1 – 7	3.53	3.50	3.63	3.80

(a) Spring Semester 2010: http://faculty.missouri.edu/~glaserr/3700s10/3700s10_evals.html.

(b) Spring Semester 2011: http://faculty.missouri.edu/~glaserr/3700s11/3700s11_evals.html.

(c) Spring Semester 2012: http://faculty.missouri.edu/~glaserr/3700s12/3700s12_evals.html.

(d) Spring Semester 2013: http://faculty.missouri.edu/~glaserr/3700s13/3700s13_evals.html.

include suggestions for improvement. 2. Compare the lecturer to others you have had (especially with those in science courses at this level. 3. List the strong and weak features of the overall course (not the lecturer) and include suggestions on how its quality might be improved. 4. Compare the course with the others you have taken. 5. Your overall rating of the course (circle letter grade): A B C D E. 6. My approximate GPA prior to the current semester was _____.

The students fill out the questionnaire toward the end of the semester and in the absence of the teacher. The teacher allocates 10 – 15 minutes of class time for the students to fill out the questionnaires and asks one student to collect the questionnaires and to deliver them directly to departmental staff. The results of the teaching evaluations (average scores to Likert scale items) and transcripts of verbatim comments to the above questions become available to the teacher after all grades are filed. It has been a practice of the first author to post all of these data (average scores and complete and verbatim student comments) online and freely accessible, and the URLs are provided as footnotes to Table 3.

The results of assessment show that this assignment-based curriculum has enjoyed a high level of acceptance by the students every semester (Table 3). The curriculum is more than accepted, it is welcome & desired! In particular, the peer review systems works very well. We believe that this high level of acceptance reflects the clarity of the purpose of the new curriculum. The learning goals of this framework are compelling and self-evident, and there has never been much need to justify this curriculum to the students. In fact, my students frequently said that they would have liked to take more courses of this type and they expressed the sentiment that taking such a course earlier in their student careers would have been beneficial.

Conclusion

As this article is being written in SP14, MU students are taking Chemistry 3700 with the theme "Nutraceuticals: Sources, Delivery, and Functions." Last week was oral presentation week with talks on a variety of dietary supplements: alpha lipoic acid, glucosamine, CoQ-10, magnesium, selenium, vitamins D and B₆, ginseng and garlic, flavones, omega 3-6-9 fatty acids, caffeine and taurine. The students needed to study the functional components of

common nutraceuticals and formulate and examine plausible scientific hypotheses regarding the claimed function of the nutraceuticals. The need for scientific literacy becomes truly self-evident when it comes to food, and our themes are selected every semester mindful of Jefferson's mandate.

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Biography

Dr. Rainer E. Glaser, studied chemistry and physics at the Universität Tübingen (Diplom 1984), at the University of California at Berkeley (Ph.D. 1987), and at Yale University (post-doctoral), and he is currently a Full Professor of Chemistry at the University of Missouri, Columbia. Glaser is a physical organic chemist with interests in optical materials, catalysis, cancer chemotherapeutics and biomimetic CO₂ sequestration. Dr. Glaser has been interested and engaged in higher education throughout his career and with focus on fostering interdisciplinary learning. In 1995, Glaser began his education research with the novel curriculum, Chemistry Is in the News (CIITN), that he designed for chemistry education of science majors with funding by the Dreyfus Foundation and by NSF. More recently, since 2009, Glaser has been serving as co-PI on the NSF-PRISM grant Mathematics and Life Sciences, and he has been developing a new curriculum to teach Scientific Writing in Chemistry both at MU and at the University of the Chinese Academy of Sciences, Beijing. Glaser has enjoyed extensive collaborations with chemists, biochemists, physicists, mathematicians, astronomers, educators and journalists in the US, Europe and Asia. Glaser was elected AAAS Fellow in 2004 and Fellow of the Royal Chemical Society in 2006.