Evaluation of the Center for Authentic Science Practice in Education (CASPiE) model of undergraduate research

Donald J. Wink,
University of Illinois at Chicago
Department of Chemistry (MC 111)
845 W. Taylor Street
Chicago, IL 60607
dwink@uic.edu

Gabriela C. Weaver
Purdue University
Department of Chemistry
560 Oval Drive
West Lafayette, IN 47907-2084
gweaver@purdue.edu

Abstract

The Center for Authentic Science Practice in Education (CASPiE) is an Undergraduate Research Collaborative supported by the NSF Chemistry Division. CASPiE has developed a model to engage first and second year undergraduates in research within traditional lab courses as part of their mainstream curriculum. The approach uses "modules" developed by university research faculty that are tied to and contribute to their research work, with support by advanced instrumentation and undergraduate peer leaders providing workshops on research skills. Information through examination of student reports, surveys, and interviews provides data for evaluation of the model, providing evidence on several dimensions that indicate program success: the nature of research appropriate for such an environment; the actual research products of the students; changes in students' thinking about chemistry, science, and their participation in STEM.

The CASPiE model for undergraduate research: A brief description

The Center for Authentic Science Practice in Education (CASPiE) is a multi-institution response to a 2003 report from the National Science Foundation and a subsequent request for proposals to provide new models for chemistry research that allow first- and second-year students to participate in research. The result is a new model for research that has been implemented at diverse institutions from community colleges to research universities. Through Fall, 2008, more than 2,700 students have done research using CASPiE materials. This is done through an approach with three key components: experiment modules for general and organic chemistry lab courses that are written by university researchers and co-developed by teaching faculty; implementation of peer-led team learning (Gafney and Varma-Nelson, 2008) in the laboratory environment; and use of research instrumentation, including where needed remote access instruments at a central, cyber-enabled facility (Weaver *et al* 2006).

This report presents some additional details of the model, including two examples of module development and our initial assessment results. We also discuss the ways in which this model of instruction links with other trends in "promising practices" (Froyd, 2008).

The Context of CASPiE

The CASPiE project is positioned at the intersection of several different trends in undergraduate education. These include the known benefits of undergraduate research for STEM students, benefits of using peer instruction, and the gains in learning associated with open-ended learning. The specific impetus for CASPiE begins with a 2003 NSF workshop report, ***Exploring the***

Concept of Undergraduate Research Centers, (Pemberton and Lee, 2003) which laid out a new vision of undergraduate research in response to the question:

> "The challenges before us in undergraduate science education are very clear: how can we provide active and engaging modes of learning such as research opportunities, with their inherent pedagogical value, to a larger number of students earlier in their undergraduate careers in a manner that will attract and retain them as majors in these disciplines?"

The NSF report was explicit about the benefits of traditional research but also reviewed how these are largely confined to a "single investigator" model of research. The successes attributable to the single investigator model of undergraduate research are linked to mentorship, being situated in actual research problems, access to equipment and space resources, and the maintenance of the project beyond the timespan of a single student's participation. At the same time, this model of research results in limitations on who can do research, since students must have time in their schedules to dedicate to in-lab time and they must generally already have acquired advanced laboratory skills before joining a research group. The workshop report called for models of research that preserve as many of the advantages of the single investigator model while transcending its limitations were needed, and these were the basis of the subsequent NSF Program Solicitation in Fall, 2003, *Undergraduate Research Centers* (URC).[1] Since then, a total of five URC's have been funded by NSF, each exploring a different model.[2]

The initial structure of the CASPiE program was a collaboration among two research universities, two comprehensive institutions, and a network of five community colleges. It has expanded since its inception in 2004 and now includes two additional research universities and, through Fall, 2008, seven community colleges. This permitted us to develop the model in conjunction with multiple teaching environments, including those where few if any opportunities exist for undergraduate research. The student diversity of the institutions provides the opportunity to study the impact of the model on underrepresented groups of students. The program has been implemented in both general and organic chemistry, impacting students in majors ranging from pre-health to engineering. Additional implementation possibilities have arisen, including the use of CASPiE as part of a summer pre-college experience and in a high school science fair context. Dissemination efforts to additional institutions not involved in the initial project and in disciplines other than chemistry are underway—a recent collaboration has resulted in funding to develop CASPiE modules for atmospheric science courses.

Details of the model

The CASPiE model for undergraduate research rests on three key elements. The first element is a set of modules written by research faculty that reflect current goals of their work. These modules cover work that can be done by undergraduates working in six to eight three-hour weekly lab periods. The modules themselves begin with two to four weeks of skill-building laboratories,

[1] The name of the program has now evolved to *Undergraduate Research Collaboratives* to recognize the need for these programs to engage in multiple disciplines and institutions.

[2] The other programs are the Ohio Research Experiences to Enhance Learning (REEL) project (Woodward and Clark, 2008), the University of Texas Freshman Research Initiative (Simmons 2008), the Northern Plains Undergraduate Research Collaborative (NPURC) (Koppang 2008) and a program centered at 2-year colleges (Higgins 2008).

which also serve as time for students to develop facility with the ideas of research and lab planning. The final three to four weeks are the research work itself, where the students are responsible for working on questions that they have developed.

The second element consists of peer-led team learning workshops to support the program. These are drawn from the very successful experience of the PLTL program in chemistry and other sciences (Gafney and Varma-Nelson 2008). The workshop materials have been adapted to focus on research skills and allow students to learn key ideas ranging from keeping a lab notebook to ethics to how to make a good presentation in an oral or poster format. The workshops themselves are facilitated by undergraduate peer leaders, trained in both the workshops and the module itself, working with a small group of CASPiE students in a discussion setting.

The third element of CASPiE consists of instrumentation. Where necessary, this consists of having appropriate equipment for students to use in their own laboratories. But, in addition, the students can avail themselves of networked instrumentation that allows, for particular modules, the efficient collection of research-quality data.

The CASPiE model and "Promising Practices"

Linkages between the CASPiE program and five of the promising practices identified by Froyd in his overview paper for the NRC Promising Practices study (Froyd, 2008) are illustrated in Table 1.

Table 1: Links of CASPiE with *Promising Practices*

Promising Practice	*CASPiE* implementation
No. 1: Prepare a Set of Learning Outcomes	The CASPiE modules share a common learning outcome as their goal: the development of students as researchers through participation in authentic research. Specific modules have their own outcomes associated with the research question (*e.g.* learning about antioxidants) or the skills needed to carry out the research (*e.g.*, attaching a substrate to a resin).
No. 2: Organize Students in Small Groups	As mentioned, the use of Peer Led Team Learning is an essential part of the CASPiE model. Peer-led groups provide an apprenticeship aspect to the program, modeling the actual practice of traditional research groups.
No. 4: Scenario-based Content Organization	The CASPiE modules all incorporate a scenario: that of the actual research project, which is usually linked to a specific "real world" problem (*e.g.*, biosensors in medicine) or a question of fundamental research (*e.g.*, reduction of organic molecules on a solid phase support).
No. 5: Providing Students Feedback through System-atic / Formative Assessment	Authentic research in almost all cases involves iteration to examine initial results prior to deciding on subsequent steps. Similarly, in CASPiE, students are graded not on the "result," but on the process by which they make decisions about what to do in their research. A specific grading rubric to support feedback on their work has been developed.
No. 7: Undergraduate Research	The CASPiE modules are research projects offered not as a supplement to traditional study but as an embedded part of the undergraduate curriculum.

The links of CASPiE to these practices are strong and arises, not surprisingly, from the fact that CASPiE was designed with attention to some of the same literature as that cited by Froyd. It is important to note that CASPiE, by design, does *not* involve close direct faculty-student interaction (Promising Practice No. 8). Rather, the module author is usually distant from the students who carry out the research. This imposes an additional burden on implementation, so that instructors and peer leaders interact with students in place of the researcher. In addition, providing the results of student research to the investigators is done through a program of online data deposition.

Goals and Specific Learning Outcomes

The CASPiE program had three major goals associated with its design and implementation. The first related to the materials development component. The second addressed the NSF goal of transforming the idea of what undergraduate research might look like, at least in chemistry. The third concerned actual impact on students, including how they view themselves and science.

The materials development goal focused on the process of producing the actual modules, PLTL workshop materials, and an instrumentation network to be used by undergraduates. Together, these form a comprehensive model for implementing research. Associated with this model are impacts on both the idea of research and the engagement of faculty. We did not want to produce materials that would be another example of inquiry laboratory work. There are already very good materials for this, but all include the idea that, although the students may experience self-direction in their work, they are engaged in asking questions about systems that are already well-understood (Fay et al 2007). Instead, the goal of our materials is to give them independence in asking and answering questions in areas where the system is not fully solved and is of active interest to the research community. There are now eight modules available for use with two others underdevelopment, as listed in Table 2. In addition, thirteen different PLTL workshops are available along with associated training materials.

Table 2 CASPiE Modules (October 2008)

Topic	**Semester**[a]	**Status**
Ion sensors using surface protection/deprotection	2, 3	ü
Antioxidants in foods	2	ü
Solid-phase organic synthesis	3, 4	ü
Band-gap tuning of ZnO_x films for solar cells	1, 2	ü
The enzyme system in dairy products	4	ü
Lipids and fatty acids	3, 4	ü
Biodiesel from waste fats	3, 4	Final editing
Small molecule antiviral drug discovery	3	Final editing
Analysis of NO_x from bio-derived diesel	3	In preparation
Soluble nanopolymers for proteomics	4	In preparation

[a.] The semester for which the module is targeted, of the first four semesters of college (1-2 in the first year, and 3-4 in the second year). Instructor discretion determines exactly which semester of their own course is most appropriate.

The goal of transforming undergraduate research had several parts, built upon the modules, the PLTL materials, and the instrumentation network. But for these to be transformational for pedagogy required that we develop effective ways of engaging students with these elements through carefully designed implementation strategies These included incorporating CASPiE into classes in different educational settings; identifying and training peer leaders for lab work; and specifying how the research results can be efficiently shared with the module author and with other students in the program. The most obvious outcome for this goal would be research publications that utilize undergraduate student work. It might also mean we could see changes in how investigators viewed their own research projects and the role of potential undergraduate researchers. In addition, though, we had to change the way faculty thought of undergraduates, to support them in developing project ideas based on their own research that would be carried out by students not under their direct supervision.

Finally, several student learning outcomes were developed. The CASPiE instructional model responded to evidence from the literature that traditional verification labs were not effective in teaching more than rote skills and calculational abilities (Nakhleh, et al., 2002). Therefore, laboratory experiences that were meaningful were a key goal. But "meaningful" in this case included both the idea of a better understanding of chemistry and the ability to carry out chemical research. In addition, we had a goal of increasing students' confidence in their ability to do research and to be able to describe their work effectively. This meant, in turn, that we had a goal of exposing students to traditional skills in planning and interpreting experiments, the idea of directing their own work, and to communication skills that reflected actual science practice more accurately.

Because CASPiE research would displace a significant amount of the traditional lab curriculum for many students, it meant that we also had to watch for certain potential negative outcomes. To the extent that lab instruction supports learning of chemistry content, for example, grades on traditional exams might suffer. In addition, the kind of learning required for successful work in CASPiE would be very different from anything students had seen before. Alienation in the face of change was a possibility.

Examples of CASPiE module use

The first module that was completed by a CASPiE module author was on the subject of antioxidants in foods. It was written by Jay Burgess from the Department of Foods and Nutrition at Purdue University. His research focuses primarily on oxidative stress in animals and the physiological results of an accumulation of reactive oxygen species. Burgess has studied the role of reactive species in the pathophysiology of attention-deficit/hyperactivity disorder (ADHD) and has shown that some children with ADHD exhibit certain biochemical abnormalities as a result of cellular oxidative stress. His work has also shown that supplementing these children with antioxidants can reverse the abnormalities and improve behavior. In other work, Burgess has been examining flavonoid antioxidants. He has determined that such antioxidants can be helpful in reducing oxidative stress, but are not sufficient to compensate for a deficiency of essential antioxidant nutrients like vitamin E. In the CASPiE module that he developed, he was interested in having students examine the effects of various type of "processing" on common foods. Processing refers to the multiple steps that a food can undergo between its natural state and the state it is in when it is consumed by a person – drying, canning, freezing, cooking, etc. It was evident to him and to us that the CASPiE setting would be an ideal one for exploring the multi-variate space inherent in this task.

Because this was the first module completed and used within the CASPiE program, it is one which provided many valuable lessons for best practices in structuring and delivering modules within a classroom setting. Initially, the author provided the students with a wide field of possibilities for them to explore and left the experimental design completely up to them. We found that students enjoyed this immensely, reaching levels of engagement within their chemistry laboratory classes that we had never personally encountered during our years of teaching. The drawback, however, was that the data from different students were so disconnected from one another that they did not form a coherent *set* from which to look for trends and draw conclusions. In the next iterations, the author learned to reach a fine balance between providing the students sufficient guidance to give him usable research data while still leaving the students with the intellectual responsibility for the experimental design and final experimental decisions. As a result, the author has now been able to capture data both on teas and on some common spices that are in preparation for scientific manuscripts.

The second case study concerns the module developed by Duncan Wardrop of the Department of Chemistry of the University of Illinois at Chicago. He conducts research in organic methodologies, including work on new methods for making libraries of compounds for study in chemical biology. As part of this, he has examined the usefulness of synthesis on a solid phase support, usually by anchoring a substrate on a modified polystyrene resin. One particular challenge he identified as very open ended: the catalytic hydrogenation of carbon-carbon multiple bonds, including olefins and alkynes. As suggested by the National Institutes of Health in a request for applications to its Centers of Excellence in Chemical Methodologies and Library Development program, "…many synthetic reactions that work well under more standard conditions are not effective under the conditions that are used for diversity-oriented synthesis, particularly if the library components (or the reagents) are attached to a solid support. As a simple example, catalytic hydrogenation using palladium on charcoal is a common, high-yielding method for reducing olefins; however, catalytic hydrogenation does not work well if the olefin is attached to a solid support."

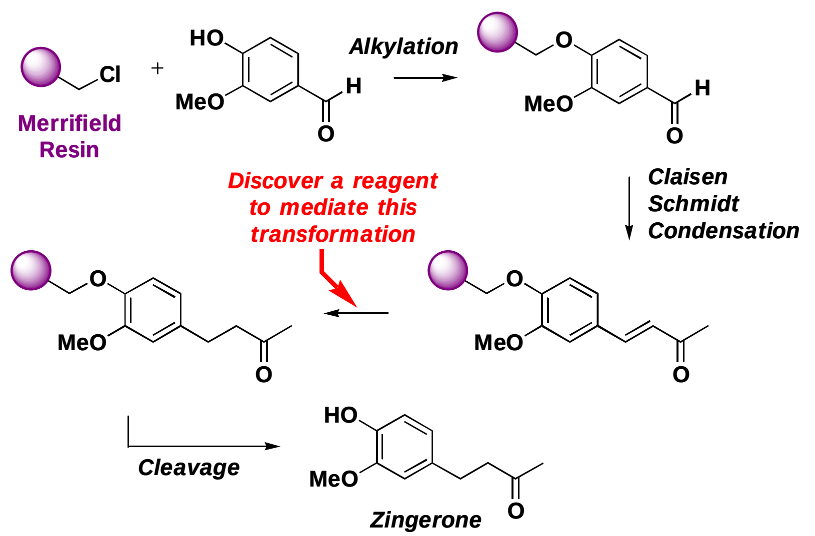

Figure 1 Key steps in original solid-phase organic synthesis module

Wardrop therefore authored a module in which students are able to take a variety of different substrates, anchor them on polystyrene, and then carry out reduction reactions. This module was developed in a pilot phase by Wardrop, a graduate assistant, and two undergraduate students in a conventional researcher setting. They introduced this to a second-semester organic chemistry course and in short order were able to confirm the effectiveness of the reactions and the ability of students at this level to carry out the multiple steps of the project. This resulted in a "training" system in which students carry out the synthesis of either raspberry ketone or zingerone on a bead (Fig. 1). In the process, Wardrop and his students also worked with the CASPiE instrumentation program to develop methods to follow the reaction in the solid phase, using Raman spectroscopy remotely.

The "solution" to this "training problem" during the pilot phase then permitted Wardrop to introduce a different substrate to students in the CASPiE module: the selective reduction of diarylalkynes to *cis*-stilbenes (Figure 2). This study has been carried out thus far entirely by students working in conventional laboratory course settings. They have developed methods to carry out the steps indicated in the dotted box in the Figure. Future work by other undergraduates will confirm if the product is present by cleaving it from the resin and fully characterizing the products.

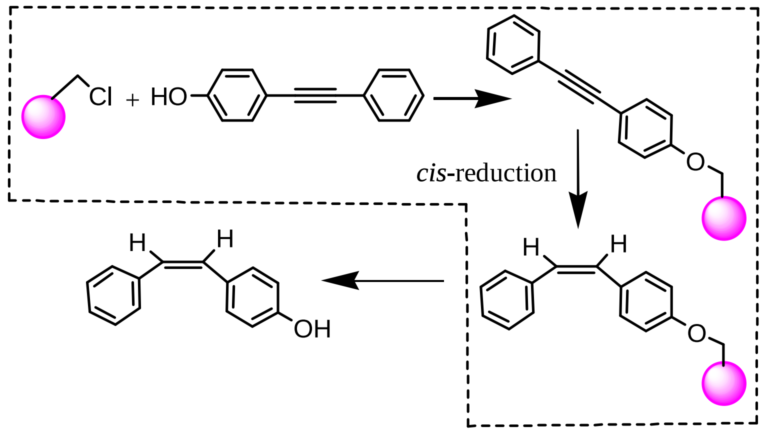

Figure 2: Key steps in alkyne reduction chemistry

Assessments of CASPiE

The goals and anticipated learning outcomes of CASPiE lab experiences, discussed earlier, required multiple forms of program evaluation. These begin with evaluation of the educational materials themselves - the modules, workshops, and instrumentation network resources.The ten modules and thirteen PLTL workshops are now under review for commercialization.

The goal of changing the picture of undergraduate research itself is assessed by considering two questions. First, have we been able to implement actual research experiences with the students? Second, are there any indications that faculty have begun to see undergraduate research in a new light, perhaps opening up new avenues of work that take advantage of this new model? The first question is answered through the progress of particular research projects. Several poster presentations of results have occurred and, by Spring, 2009 there should be multiple examples of CASPiE-generated student research results in papers in peer-reviewed journals.

The question about research itself is broader and must be assessed over time. But the shape of an answer can be seen, for example in the way in which antioxidants data is being used by Burgess. In addition, new research ideas are being developed as faculty become familiar with the idea of collaborations with undergraduates. In Spring, 2005, Kenneth Brezinsky of the UIC Department of Mechanical Engineering was contacted to serve as a contact for a module in biodiesel synthesis, developed at Northeastern Illinois University. He provided important background information to the group. But at the same time he developed the idea that, for his own research, CASPiE student researchers could engage in a distributed solution to the problem of providing high-quality quantities of a set of model compounds for his work. These compounds (based primarily on esters of linear unsaturated eight-carbon carboxylic acids) are known, but efficient syntheses of multigram quantities have not, in many cases, been developed. Beginning in winter, 2009, Brezinsky's NO_x modeling project will have use of these materials; in turn, students in organic chemistry will be carrying out new research. Together, this represents an example of a new relationship between a faculty member and collaborative researchers—in this case, undergraduates in organic chemistry.

Finally, the most important goal for the current Promising Practices project concerns student learning outcomes. The evaluation of these has had, to date, three components - two quantitative and one qualitative.

First, to answer the question of impact on learning (including the threat that the removal of conventional lab work would result in a loss of content learning for exams), a quasi-experimental study was conducted during a general chemistry course at a large research university. Students in one section of the course received conventional labs for the entire semester while those in the other did the same conventional labs for the first half of the semester, then a CASPiE module for the second half of the semester. Both sections had the same lecturer and assessments. The students were determined to be equivalent based on entry parameters and their scores on the first two hourly exams (prior to the introduction of differentiated lab experiences). On the third hourly exam and the final there were no significant difference on exam performance, *despite the fact that the students receiving CASPiE had seven fewer course-connected lab experiences*.

In addition to the course results, we are also able to assess differences between participant and non-participant groups through a survey developed to assess student attitudes towards chemistry and learning through the lab. The survey, developed in collaboration with the Evaluation and Assessment Center of Miami University, has 30 6-point Likert scale items. Item-level analysis to compare the outcomes of the CASPiE experience with traditional labs was done. For the following items, CASPiE participants (N = 188) reported higher agreement than non-participants (N = 210) at a statistically significant level:

- I have a better understanding of the process of scientific research as a result of the laboratory experiences in this chemistry course.
- The lab experiences in this chemistry course made me realize I could do science research in a real science laboratory (for instance at a college, or with a pharmaceutical company).
- Even if I don't end up working in a science related job, the laboratory experience in this chemistry course will still benefit me.
- The lab experiments in this chemistry course presented real science to students, similar to what scientists do in real research labs.
- The concepts covered in this laboratory course are relevant to the real world.
- I believe I could accurately explain a chemistry experiment from this course to other students.

- I believe I could accurately explain a chemistry experiment from this course (including the significance of the results) to my instructors.
- The lab experience in this chemistry course has made me more interested in science // a science career // earning a Masters degree in a science field.
- In my life, I will use skills // knowledge I've learned in this chemistry laboratory course.
- Finding answers to real research questions motivated me to do well in the chemistry lab.

On the other hand, participants were significantly less in agreement with the statements:

- In this laboratory course, I can be successful by simply following the procedures in the lab manual.
- I think that lab experiments in this chemistry course were well organized.

Taken together, these results indicate that, with the same instructor, course topics, and exams, CASPiE participants learn chemistry as well and also report significant shifts in their perception of the authenticity and relevance of their lab. There are also indications that they have increased their ability to communicate the meaning of their work, despite the absence of prescribed steps in their lab manual.

The second quantitative study also uses the survey but combines items to support factor-level analysis with Rasch modeling (Boone & Scantlebury 2006).. There is high individual inter-item reliability (Cronbach's $\alpha = 0.948$) for the full survey and a factor analysis identified six areas where particular questions could be grouped meaningfully (see Table 3). The survey has now been administered systematically over two different academic years. For the purpose of our primary evaluation questions, only those cases where we have a matched pre- and post-survey from the same student are included in the data set. In the two years of systematic study with the validated survey (2006-7 and 2007-8) there have been 1920 students in the database who have completed valid pre- and post-surveys, representing more than half of all CASPiE participants.

Table 3 (next page) shows the information available for the post-survey results for six major factors identified in the survey for both years of systematic work. The data are reported as Rasch mean scores. These report the result of a Rasch modeling analysis applied to all of the questions that contribute to the factor. Results are initially normed at a mean score of "50," regardless of the absolute value of the Likert-scale averages. This permits a much more accurate understanding of changes in overall results over time, meaning that we can be confident that a "+5" difference on one factor is as meaningful as the same difference on a different factor. It also permits the comparison of data over time. In Table 4 those factors (column 1) shaded with blue and in italics font have a statistically significant difference between the participants and non-participants in one or both years. Those data cells (columns 2-5) that are shaded with yellow and with bold font show a statistically significant *increase* between the pre- and the post-survey results for that group of students and those data cells shaded in green and underlined show a statistically significant *decrease* between the pre- and post-survey.

Table 3 Rasch mean scores for student survey factors (Pre-survey / post-survey)

	2006-7		2008-9	
	Participant	Non-Participant	Participant	Non-Participant
N	611	680	181	348
1. Interest in chemistry / science	<u>48.95 / 42.17</u>	<u>47.83 / 42.10</u>	56.75 / 57.84	<u>47.71 / 42.86</u>
2. Real life and science	50.40 / 49.08	<u>49.41 / 46.94</u>	**54.91 / 59.84**	<u>51.00 / 47.28</u>
3.Authentic scientific lab practices	**49.13 / 53.74**	<u>50.18 / 47.12</u>	**54.03 / 67.66**	50.47 / 49.60
4. Perceptions of learning through laboratory	50.23 / 49.72	<u>49.72 / 47.40</u>	55.58 / 55.52	50.21 / 49.13
5. Belief in chemistry knowledge	<u>54.32 / 52.18</u>	<u>52.07 / 49.49</u>	**61.46 / 63.09**	<u>54.26 / 51.51</u>
6. Collaborative learning in courses	57.75 / 58.88	59.99 / 59.09	55.68 / 58.49	58.77 / 58.49

Key: Yellow shading / bold text = significant increase from pre- to post-survey; green shading / underlined text = significant decrease from pre- to post-survey; blue shading / italic text = significant role of participation or non-participation in change from pre- to post-survey.

Several trends are apparent in Table 3 and more detailed data on changes between pre- and post-survey results. All of the following points are statistically significant ($p < 0.05$) according to the relevant analysis (*t*-test for single comparison and two-way ANOVA for two-variable changes).

- **For Interest in Chemistry / Science.** For 2006-7 there was a decrease in this factor for both participants and non-participants. But in 2007-8 the decrease only occurred for non-participants. Participants started with a significantly higher score and this was maintained. There was a significant dependence for the pre / post change in this factor depending on whether someone did a CASPiE module.
- **For Real Life and Science.** For both years, the change in this factor depended on whether someone did a CASPiE module, with the score for CASPiE participants either maintaining (2006-7) or increasing (2007-8) while it decreased for non-participants.
- **For Authentic Scientific Lab Practices.** For both years, the change in this factor depended on whether someone did a CASPiE module, with the score for CASPiE participants increasing in both years, in 2007-8 by fully 13 points. The score decreased for non-participants for both years.
- **For Perceptions of Learning through Lab**. There was an effect of participation in 2006-7 with a decrease for non-participants but not for participants. There was no effect of participation on this factor in 2007-8.
- **Belief in Chemistry Knowledge**. There was a decrease in this value for both groups in 2006-7, though there was no effect of participation. In 2007-8 there was again a decrease for non-participants but there was an increase for participants. Participants also started higher on this score in 2007-8.

- **Collaborative Learning in Courses**. There were no significant effects or differences for this factor.

Along with more detailed analysis (comparing gender, ethnicity, institution type, and course level), we use these data at this point in a formative manner. Specifically, we feel that there are good indications that CASPiE "does no harm" in terms of either actual student performance or their perceptions of their ability to progress as chemistry students with CASPiE in place of conventional labs. On the other hand, we have seen some significant differences associated with both direct ("Authentic Scientific Lab Practices") and indirect ("Interest in Chemistry / Science" & "Real Life and Science") measures that suggest that we are achieving our goal of changing how students view chemistry and the meaning of chemistry to them. Changes between the two years may also reflect our own experience in supporting the implementation of CASPiE, as we learn better how to explain its components and goals to students and instructors.

The third component of the evaluation is qualitative. Focus groups and interviews are included in this research to address particular questions. Research in the Weaver group by Cianán Russell looked in particular for differences among three types of lab program: traditional labs, CASPiE, and a well-established inquiry lab program (Abraham & Pavelich, 1999). This study was carried out by comparing interview and survey data from students at five different institutions implementing one or more of the three types of curriculum (Russell, 2008; Weaver *et al* 2008). A total of 899 student surveys and 50 student interviews were analyzed and compared along the dimensions of content comprehension (main idea of the experiment, description of experimental results and proposed next step for an experiment) and nature of science (experiments, theory, evidence and creativity). With respect to the content comprehension components, the laboratory experience had no discernable effect on the students in the traditional curriculum, had a minor increase on the students in the inquiry curriculum, but only with respect to explaining the main idea of their experiment, and showed marked increases for students in the CASPiE curriculum. Tables 4-6 describe these effects quantitatively for the students interviewed.

Table 4. Summary of changes in ability to describe the main idea by interview and curriculum

	No change		Negative change	Positive change
	Consistently unclear	Consistently clear	Clear to unclear	Unclear to clear
Traditional	50%	30%	10%	10%
Inquiry	0%	44%	11%	44%
Research	0%	42%	8%	50%

Table 5. Summary of changes in ability to describe the results by interview and curriculum

	No change		Negative change	Positive change
	Consistently unclear	Consistently clear	Clear to unclear	Unclear to clear
Traditional	54%	36%	10%	0%
Inquiry	56%	33%	11%	0%
Research	14%	39%	4%	43%

Table 6. Summary of students' experimental next steps by interview and curriculum

	Entrance			Exit		
	Don't know / Would not do one	Repeat experiment	Extension of experiment / Complex response	Don't know / Would not do one	Repeat experiment	Extension of experiment / Complex response
Traditional	50%	30%	20%	70%	20%	10%
Inquiry	45%	33%	22%	22%	67%	11%
Research	47%	32%	21%	0%	34%	66%

Along the dimensions of the nature of science measures, students in the CASPiE curriculum demonstrated a richer understanding of the use and development of scientific theories and described an appreciation for the role of creativity in the experimental process.

Next steps for development and dissemination

The CASPiE program is now at a point where generalized dissemination has begun. During the previous four years, CASPiE modules have been developed and used in a wide variety of institutions. Implementation at community college, comprehensive, and research university sites was an essential part of the initial design of the program. Within these institutions the modules have been used at a variety of scales. In some cases, modules have been implemented with sections of 15-30 students under the supervision of the course instructor. In others, we have seen that the modules can be used with research university general chemistry sections of more than 550 students at a time, including the processing of over 1200 HPLC samples through the instrumentation network. In addition, the network of participating institutions has grown significantly to include other community colleges, research universities, and a university in Australia.

It is also interesting to note that CASPiE modules have been used in other teaching environments, indicating the potential for this model of research to address needs that were not anticipated in the initial program. These include, for example, the use of modules as part of a pre-college "bridge" program for incoming students at a research university; implementation in disciplines besides chemistry; and adaptation of CASPiE for use in high school environments, especially as components of either AP or science fair curricula.

With evidence of how to implement the CASPiE model of undergraduate research effectively within all types of higher education laboratory curricula we are now turning to a dissemination phase. This has begun with our initial set of additional partners and has been extended to a more formal workshop-based dissemination strategy. During summer, 2008, we hosted both one-day workshops (at the Biennial Conference on Chemical Education) and a full-week residential workshop (in cooperation with the Center for Workshops for the Chemical Sciences, which provided partial funding and logistical support). Participants in these workshops and others were then invited to submit requests for implementation mini-grants; the initial set of these has now been received. Plans for a more extended program for studying CASPiE modules at additional sites, including possible full national dissemination, are underway.

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