Integrating High Performance Computing into the Undergraduate Curriculum:
How PACI and the Education Center on Computational Science & Engineering Can Succeed

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Abstract

The Education Center on Computational Science and Engineering at San Diego State University assists the Partnership for Advanced Computational Infrastructure (PACI) in its goal of encouraging the integration of high performance computing technology (HPC) into the undergraduate curriculum. Because the means by which to best effect the undergraduate curriculum are still unclear, EOT-NPACI, which provides part of the Center's funding, asked the LEAD evaluation team to evaluate SDSU's Education Center over its second year of operation (1998-99). This report summarizes what was learned during LEAD's evaluation regarding the obstacles to incorporating HPC-based instruction into the undergraduate curriculum and the strategies that have the highest probability of overcoming these obstacles. Among the strategies that hold the most promise are programs like the Education Center's Faculty Fellows program, which provides buyout time, technical and logistical support, and a community of curricular reformers to work with faculty who are attempting to integrate HPC instructional modules into their own curricula. Many of the challenges that the Education Center faces are similar to those faced by other EOT-PACI programs, and as became apparent from the evaluation described here, the help of PACI's HPC tool developers will be needed to overcome some of these challenges.

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1. Introduction: Increasing the accessibility and usability of HPC technology

The overarching mission of the diverse programs that comprise the Education, Outreach, and Training Partnership for Advanced Computational Infrastructure (EOT-PACI) is to ensure that all citizens have the opportunity to make productive use of emerging computing technologies that advance our ability to understand and solve problems in science, education, business, government, and the environment. In other words, EOT-PACI programs seek to make high performance computer technology (HPC) more accessible and more useful to as many people as possible, not just the computational scientists and industrial researchers who have traditionally used HPC. As HPC becomes an ever more integral force in allowing the creation of data-rich models and visualizations and the manipulation and exchange of audio/video over the Internet, the need to expand the awareness and technical skills of potential users becomes ever more pressing. EOT-PACI seeks to ensure that all sectors of society which might benefit from HPC technology have ample opportunity to learn about, use, and effect the development of these increasingly widespread problem-solving and communication tools.

One area in which EOT-PACI hopes to provide greater accessibility to, and understanding of, HPC is in undergraduate classrooms, where the next generation of HPC users is receiving their first specialized training in the scientific and computational disciplines. The undergraduate curriculum is a natural and important place to begin expansion of the HPC user-base, but there are many challenges to bringing HPC into university and college classrooms. These challenges must be understood and creatively addressed if EOT-PACI is to succeed in its goal of integrating HPC tools into the undergraduate curriculum in a meaningful and productive way.

2. The known challenges to bringing high performance computing into the undergraduate classroom

The challenges to integrating HPC technology into the undergraduate curriculum fall into two broad categories: challenges for universities and colleges in providing instructors with the technological and human infrastructure needed for high performance computing, and the challenges that computer-based instruction poses for individual faculty members. The challenges at the university and college-wide level must generally be addressed first, since computer-based instruction cannot proceed at all without the proper technological resources. But the remaining challenges, those posed to individual faculty members who must decide whether or not to incorporate computer-based tools into their teaching, are no less daunting. Indeed, while universities are making steady progress in improving their technological infrastructure to allow convenient computer and Internet access for students and faculty alike, assisting faculty in finding useful ways to integrate computer technology into their teaching remains the single most important technology issue confronting most institutions (Campus Computing, 1998). Hence, while this report devotes some attention to the issue of improving universities' technological and human infrastructures (Section 2.1), the bulk of the report focuses on the more complicated issue of encouraging and supporting faculty in their efforts to find a meaningful place for HPC in their undergraduate curricula.

2.1 University and college-wide challenges in providing the technological and human infrastructure for high performance computing

Earlier in this decade, many institutions of higher learning were debating whether to invest in providing campus-wide access to computers and the rapidly growing world of information and global communication available through the Internet. As many experts point out, equipping an entire campus with up-to-date computers and networking capabilities is neither politically simple nor cheap (Neal, 1998; Bedwell-Brace & Roberts, 1997). Yet today, the debate over making such investments has been all but drowned out by the roar of Internet traffic on the nation's college campuses. As the annual Campus Computing survey (1998) illustrates, universities that don't provide computer and Internet access to students and faculty are becoming increasingly rare. As a result, although gaps in universities' technical infrastructures still exist, getting access to computer networks in classrooms, laboratories, and even dormitories is less of a problem with each passing year. What's more, an increasing number of college instructors are taking advantage of that access. While just 15.3 percent of college courses had Internet resources in their syllabi in 1996, by 1997 that percentage had climbed to 24.8, and by 1998 the percentage was 33.1 (Campus Computing, 1998).

However, in spite of the considerable progress universities have made in providing computer and Internet access, significant barriers to computer-based instruction still exist at the institutional level, including: inadequate technical support or technical training for faculty members; time constraints that make it difficult for faculty to learn how to use new technologies; and a general lack of knowledge about how to best integrate these materials into the curriculum (Campus Computing, 1998). The first of these obstacles—lack of technical training and technical support staff—underscores the point made by many experts in technological reform: that developing the "human infrastructure" for educational technology is as important as developing the technical infrastructure, and that both require a sustained and substantial commitment of time and financial resources (Green & Gilbert, 1995; Northover, 1999; NSF, 1996). Institutions often underestimate both the costs and the time frame for bringing about significant and effective computer-based reforms. Successfully integrating technology into the standard curriculum takes years, not weeks or months (Green & Gilbert, 1995). Experts at an NSF workshop on instructional technology reforms (1996) said even 3 to 4 years may be too short a time in which to determine whether an institution's computer-based reform is "working." Institutions of higher education must take this into account and not withdraw support for a technological reform before it has really had a chance to "take hold" and start paying off.

2.2 Faculty concerns affecting the use of high performance computing in instruction

In the past, high performance computing applications could only be used by those who had access to supercomputers or high-powered workstations. But now that many HPC resources are available over the Internet, every college instructor and student who has a high-speed Internet connection becomes a potential user and beneficiary of HPC technology. This means that the larger challenge in bringing HPC resources into the undergraduate curriculum is persuading the faculty and students in various disciplines of the usefulness and relevance of HPC technology.

University administrations in general may have decided to buy into the computer revolution, but in most institutions, it is individual faculty members who must decide whether and how to make use of the technological resources the university has provided.

While some departments have fixed or standardized curricula for certain courses, most give their faculty a great deal of latitude in deciding what and how to teach for a given course. There are many factors which go into this decision, and understanding these factors is critical in assisting individual faculty members in weighing the potential costs and benefits of using HPC applications to teach certain concepts. EOT-PACI, like any other group that is trying to find a worthwhile role for computers in the undergraduate curriculum, must be aware of existing faculty concerns regarding the use of computers in education and must have viable strategies to address those concerns. Simply providing computer and Internet access only goes so far in encouraging college instructors to incorporate computer-based lessons into their teaching. In this section, we review some of the relevant literature on how faculty have responded to instructional technology reforms in order to delineate the challenges faced by the EOT-PACI programs that work with these faculty.

The factors which underlie faculty resistance to the use of instructional technology, as presented in numerous texts including Cravener (1998), Cummings (1995), Noblitt (1997), and Northover (1999), are remarkably similar to the factors which underlie faculty resistance to educational reforms in general (see Hutchinson & Huberman, 1993, for a review). The most frequently mentioned reasons for why faculty are reluctant to incorporate computer-based instructional materials into their courses are:

- a lack of convincing evidence that using computer-based instructional materials will allow students to learn more, learn more quickly, or learn better;
- a lack of knowledge about which computer tools are the most effective for their needs and how these tools could be incorporated into their curricula;
- a lack of the necessary computer skills and a lack of time to learn those skills;
- a lack of incentives from departments and colleges to pursue the use of educational technology;
- the presence of powerful disincentives for trying something new in the classroom, like the possibility that taking the time and effort to pursue teaching reforms will impair their research efforts and be frowned upon by tenure review committees;
- inadequate institutional support for their efforts in the form of technical infrastructure, ongoing and readily-accessible technical support, and release time to develop and refine the use of computer materials.

Addressing these faculty concerns is a complicated task that requires an understanding of how universities operate and a willingness to work towards reform systemically (i.e., at several different levels simultaneously). Reformers must work not only with individual faculty at the course level, but also with department chairs and tenure committees at the departmental level, and college or university administrators at the institutional level. For although it is individual faculty who will choose whether or not to pursue a technological reform, that choice will be strongly affected by the implicit or explicit approval of the faculty member’s college or department. For faculty members and administrators alike, the critical question is: Will the time and effort spent by a faculty member on this reform be worth the benefits that the students and or/faculty member gain from it?

Answering skeptics' questions about the value of pursuing a technological reform, the costs and risks involved in doing so, and the pedagogical adjustments required, involves three separate strategies: The first strategy is to provide demonstrations or first-hand accounts from respected faculty members of how the technology in question allowed them to improve student learning or student engagement in the courses they taught. As Noblitt (1997) and faculty experts at an NSF workshop on information technology (NSF,1996) have argued, faculty members are trained skeptics who need convincing evidence of the value of an innovation before they are willing to try it. Research on faculty change and the dissemination of reform in higher education has found that personal contact with a respected colleague who has tried an innovation is the means by which most successful reforms are spread (Foertsch et al, 1997; Hutchinson & Huberman, 1993; Rogers, 1995). Similarly, the most convincing form of evidence for faculty members is a hands-on demonstration by that colleague who has actually used the innovation (Foertsch et al, 1997; Hutchinson & Huberman, 1993; Noblitt, 1997; NSF, 1996). Ideally, this demonstration should be supported by classroom assessments, evaluations, or faculty observations that demonstrate the innovation had a positive impact on students' engagement, conceptual understanding, or ability to articulate what they learned. Noblitt (1997) makes the point that innovations must do more than just "work": They must work *substantially better than* or provide a fundamentally *different kind of understanding than* the form of instruction they are meant to replace. Unless a technological innovation provides a real "added value" educationally, faculty members have little incentive to take on the costs and risks associated with making a curricular change. Unfortunately, as anyone familiar with the reform process knows, it can take several iterations before the changes in a given course demonstrate a measurably positive impact (NSF, 1996).

The second strategy for making a technological reform seem worthwhile is to present information from research studies and news reports that suggests a curricular or pedagogical change is necessary in order to adequately prepare students for the demands of current or future job markets. Because the use of information technology has become ubiquitous in most employment fields and because computer skills give job seekers an edge in almost every market, educational reforms that make use of computer technology have one inherent advantage over other types of educational reform: They make students into more marketable employees, even when it is unclear that they make students into better learners. A number of scholars (Cravener, 1998; Ehrmann, 1995; Kozma, 1994; NSF, 1996; Weller, 1996) have argued that in the right pedagogical contexts, computer-based instructional materials can lead to a variety of benefits for current students and future employees. The most frequently mentioned benefits are the following:

- Computer-based learning tools can enable students to visualize, model, and experiment with complex, real-world scientific problems, thus promoting exploratory and inquiry-based modes of learning—the same type of learning employed by researchers in the field and modern-day employees on the job.
- Instructional technology can facilitate collaborative, interactive learning and approximate more closely the collaborative work environments that many students will eventually face.

- Information technology can facilitate communication across disciplinary, institutional, and geographical boundaries—the same sort of intergroup communication that is often necessary to find solutions to complex problems in real-world contexts.
- Information technology can provide convenient access to a broad assortment of the most current information resources worldwide. This access reduces student reliance on textbooks and paper resources that may be outdated or less well-tuned to their needs.

Of course, as research and literature reviews by Ehrmann (1995), Kozma (1994), and Weller (1996) have demonstrated, the benefits to be realized in using computer-based instructional materials depend as much on the *way* they are used as on the quality of the materials. For technological innovations to succeed, they must be coupled with pedagogical and curricular changes that make the most of the technology's capabilities to provide information or demonstrate concepts in ways that are engaging, informative, and well-attuned to a student's learning style and educational interests. According to the NSF (1996), the most effective applications of educational technology are those that:

- stimulate students and engage them with the material;
- illustrate the workings of complex or normally invisible systems by allowing interactive exploration of cause-and-effect relationships, simulations, and hypothetical scenarios;
- encourage collaboration among students, researchers, or faculty members, and facilitate the coordination and communication needed for a group effort;
- foster the development of critical thinking skills, visualization, conceptualization, integration of disparate data, and resolution of patterns within data;
- utilize the Internet for research and posting of material.

The third strategy for making a technological innovation seem worthwhile is focused on the practical skeptic's question of, "What's in it for me?" In order to feel comfortable pursuing time-intensive curricular changes, many faculty need some degree of assurance that their efforts will be rewarded—or at least not frowned upon—by their departments, institutions, or professional colleagues. Hence, the third strategy for encouraging technological innovations is to promote and gain support for those innovations from university administrators, college deans, department chairs, and faculty review committees. Such support is not only important in encouraging faculty to attempt innovations, but is essential to ensuring these innovations will be institutionalized and have a measurable impact over time. (Cravener, 1998; Cummings, 1995; Green, 1996; Millar, 1999; NSF, 1996).

2.3 The educational niche that HPC can fill: Visualization and modeling

Those who wish to encourage the use of high performance computing in the instruction of undergraduates must overcome the misunderstandings and lack of knowledge that discourage many otherwise reform-minded faculty from even considering the use of HPC. HPC-based reforms are particularly difficult to encourage because, as Kiernan (1998) has illustrated, many faculty members have no conception of what high performance computing or "supercomputing" involves, much less how they could make use of it. Hence, in addition to the suggestions made in Sections 2.2, there are two essential tasks that must be undertaken by EOT-PACI groups working in education: The first is to make clear the distinction between high performance computing applications and other forms of educational technology. The second is to draw attention to the educational niche that HPC can fill and fill well: providing interactive visualization, modeling, and data-manipulation tools that can engage students' interest, facilitate their conceptual understanding, and provide hands-on experience in solving the sorts of complex, open-ended problems that scientists and other researchers encounter in the real world.

The first effort is necessary because many faculty members lump all forms of "ed tech" into one pile. As a result, if faculty members are threatened by one form of educational technology (like distance education) or fail to see the pedagogical value of another (like PowerPoint presentations or Internet searches), they will likely be turned off by educational technology altogether. It is important for the promoters of HPC-based applications to make clear what HPC really is—and what it is not. Examples and demonstrations of actual applications are useful in this regard. The article by Kiernan (1998) and LEAD Center research undertaken for this report suggest that it is generally unwise to associate HPC applications with "supercomputing" when talking to the majority of faculty members, since the mention of "supercomputers" often suggests to them "more power than I'll ever need and more trouble to learn and access than it's worth." References to "digital libraries" and descriptions of how students can analyze huge real-world data sets using workstations will interest some undergraduate instructors, but most instructors feel they can teach the same concepts using the smaller datasets found in textbooks or using data that the students have collected themselves. Our research and our review of the literature suggest that the interactive visualization and modeling capabilities of certain HPC applications are more likely to capture the interest of faculty members who are unfamiliar with HPC.

Dede et al (1998) believe that faculty members will ultimately find high-end applications of educational technology like visualization and modeling tools more compelling and useful than low-end applications like PowerPoint and e-mail, which seldom improve upon the non-technology-based practices they are meant to replace. As Noblitt (1997) argues, a technology-based solution can't just be different—it must be better. Technology is seen as a means to an end, and if this end is already being accomplished through other, cheaper means, faculty members will have no interest in learning how to use educational technology to get to the same place. Promoters of educational technology need to look for unmet needs: What does this computer-based tool allow instructors to do that they aren't already doing in the classroom?

For HPC, the answer lies in promoting these tools' ability to allow students to visualize, model, manipulate, and experiment with real and virtual complex systems. A number of researchers who have developed interactive visualization and modeling tools to teach scientific concepts argue that these tools fill an important niche in science and math education (Dede et al, 1998; Goldberg & Bendall, 1995; Land & LoPerfido, 1993; Williamson & Abraham, 1995). First, they allow students to "see" and conceptualize normally invisible phenomena and gain first-hand familiarity with the scientific laws that explain them (Dede et al, 1998; Goldberg & Bendall, 1995; Land & LoPerfido, 1993; Williamson & Abraham, 1995). Second, they allow students to better understand and gain hands-on experience with counterintuitive scientific principles (Dede et al, 1998; Goldberg & Bendall, 1995; Land & LoPerfido, 1993). Third, they allow students to progress through material at their own pace, repeating demonstrations as needed and exploring different approaches or pathways as desired (Goldberg & Bendall, 1995; Land & LoPerfido, 1993; Williamson & Abraham, 1995). Fourth, in the case of virtual reality (VR) applications, they allow students to use multiple sense modalities to perceive, comprehend, and encode information about scientific principles, increasing the likelihood that these principals will be intuitively understood and recalled (Dede et al, 1998). When appropriately used and sufficiently integrated into a course's curriculum, these modeling and visualization tools can produce significant gains in students' conceptual understanding of, interest in, and engagement with course content (Dede et al, 1998; Goldberg & Bendall, 1995; Land & LoPerfido, 1993; Williamson & Abraham, 1995). While other applications of high performance computing are also likely to gain faculty support over time, the applications that involve interactive visualization and modeling will probably be the first to find their way into the undergraduate curriculum.

3. The purpose of LEAD's evaluation of the Education Center on Computational Science and Engineering

One EOT-PACI program that seeks to integrate HPC technology into the undergraduate curriculum using some of the strategies mentioned in Section 2 is the Education Center on Computational Science and Engineering (EC/CSE) at San Diego State University (SDSU), a university in the California State system with a strong emphasis on undergraduate education that serves some 30,000 ethnically-diverse students. The Education Center opened in October 1997 with joint funding from the NPACI/SDSC branch of EOT-PACI, the Office of Academic Affairs at SDSU, and the California State University system. The Center employs a director, a staff scientist, an administrative assistant, and 4-6 graduate and undergraduate student workers. The stated mission of the Education Center is to foster the incorporation of HPC research tools into the undergraduate curriculum in order to better prepare learners for arenas where collaborative interdisciplinary teams, sophisticated computer tools, and effective intra- and inter-group communication are used in research and problem solving." From our discussions with Center Director Kris Stewart, we discovered the supporting goals of the Education Center to be the following (listed in the approximate order in which they need to be achieved):

1) To make faculty and researchers at SDSU aware of the HPC resources and support available through the newly-created Center.
2) To encourage and support SDSU faculty in a wide variety of disciplines to develop curricula that use HPC applications in teaching disciplinary content, research skills, and computer skills.
3) To provide an outlet for HPC applications suitable for undergraduate education developed by the collaborating partners in PACI, and to introduce the public (i.e., college students) to what these computational resources can do.
4) To increase the number of faculty and students at SDSU who are familiar with PACI's HPC tools and use them in their research or coursework.
5) To serve as a model for computational science education centers to be developed at other campuses throughout the nation. If SDSU's Education Center proves to be an effective change agent locally and the reasons for its effectiveness can be understood and documented, it could be expanded or replicated to offer support for the entire California State University system, potentially affecting a highly-diverse student population of over 225,000 students.

Since PACI is very invested in outreach to undergraduate education but the means by which to best effect the undergraduate curriculum are still unclear, the EOT-NPACI leadership asked the LEAD Center to evaluate SDSU's Education Center over its second year of operation (1998-99). The goals of the LEAD Center evaluation, funded through the NPACI branch of EOT-PACI, were:

- To provide a year of formative feedback to Education Center administrators on the Center's progress in achieving its goals and recommend ways to make the Center more effective and more efficient in achieving those goals.
- To provide year-end summative feedback that would enable Center personnel, stakeholders, and funders to see how effective the Education Center has been in its second year of operation and to share the lessons learned through the evaluation.

It should be noted that many of the lessons learned from LEAD's evaluation apply not only to the Education Center, but to any HPC outreach program working with undergraduate education—and these lessons are of value to PACI as a whole. Many of the challenges that the Education Center faces are similar to those faced by other EOT-PACI programs, and as became apparent from the evaluation described here, the help of PACI's tool developers will be needed to overcome some of these challenges.

4. Design and methodology of the evaluation

In evaluation terminology, LEAD's evaluation of the Education Center on Computational Science and Engineering was more "formative" than "summative," as would be expected with a program that is still in its initial stages of development. In a formative evaluation, the evaluators work closely with program administrators throughout the year to monitor their strategies and provide continual feedback on these strategies' effectiveness. Initially, such an evaluation involves collecting baseline data on the program's potential client-base (in this case, professors at SDSU), what those clients' needs are, and how best to proceed in addressing those needs. Once strategies are implemented, the evaluation enters a reiterative process of collecting data, analyzing it in the context of what is already known, and sharing the results with program administrators through formative feedback meetings and reports. Our discussions with Education Center administrators throughout the year helped us to refine our later data collection, just as the data we collected helped them to refine their strategies and develop new ones as needed. At the end of the year, we compiled all of the data in order to share with stakeholders the most important of the lessons learned. This year-end analysis, though "summative," should not be used to draw any strong conclusions about the effectiveness of the Education Center in the long term. The Education Center is very much a work-in-progress, and as experts at the NSF workshop on instructional technology reforms have argued, it can take at least 3 to 4 years to determine whether a program like the Education Center is "working" (NSF,1996). To assist in the long-term evaluation of the Education Center, the LEAD research team has provided Center administrators with databases and faculty surveys that will allow them to self-evaluate their progress in the years to come. We have also provided them with course evaluation survey templates that will allow SDSU professors to assess the impact of HPC-based instruction on the students in their courses.

The evaluation of the Education Center was carried out from July of 1998 through June of 1999. During this time, the LEAD evaluation team performed the following evaluation activities:

- An initial planning evaluation comprising an assessment of goals, strategies, and proposed evaluation activities with Education Center Director Kris Stewart;
- First and second-semester interviews with Kris Stewart and Education Center Staff Scientist Ilya Zavlavsky regarding the Center's strategies and activities each semester;
- A survey of SDSU faculty from the three colleges with which the Education Center is working (Arts & Letters, Engineering, and Sciences) regarding faculty computer needs, computer-based instruction, knowledge of HPC, and knowledge regarding the Education Center (see Appendix A for a copy of the survey). Of the 461 faculty surveyed, 175 responded, for a response rate of 38% (66, or 30%, of the College of Art & Letters responded; 25, or 58%, of the College of Engineering; and 84, or 43%, of the College of Sciences). This sample was representative of the total faculty population for these colleges in terms of gender, years teaching, and tenure status;
- Semi-structured inductive interviews with SDSU's Associate Vice President of Academic Affairs, with an Engineering instructor using virtual reality HPC applications in his courses, and with the college deans for the three colleges with which the Education Center is currently working (see Appendix B for an example of the interview protocols);
- Semi-structured inductive interviews with 10 department chairs: 4 from departments where the Education Center had already begun working and 6 from departments that the faculty survey had indicated were the most receptive to HPC use in the classroom (See Appendix C for an example of the interview protocols);
- A review of relevant literature on the topics of faculty change, faculty resistance and institutional obstacles to computer-based instruction and HPC, strategies for overcoming obstacles to computer-based instruction and HPC, and the benefits of using HPC visualization tools and virtual reality to teach scientific concepts;
- Three formative feedback meetings with Education Center administrators where we provided them with written reports and engaged in discussions regarding our analyses of survey results, Dean interviews, Department Chair interviews, and the literature review;
- Assisted Kris Stewart in modifying and adding to the surveys she is using to evaluate her Computer Science 575 (supercomputer programming) course.
- Conducted year-long case studies with the 3 Faculty Fellows who were funded by the Education Center to develop HPC tools for their curricula and take their newly-developed tools into the classroom. These case studies included individual interviews with the Fellows at three points during the year, a review of the course materials and presentations posted by each Fellow on the Education Center's website, and observations of two of the bi-weekly Faculty Fellows Meetings held at the Education Center;
- Revised LEAD's faculty survey based on the first year's results and provided the updated version and database to the Education Center so that they may re-administer the survey in upcoming years to assess the Center's impact over time;
- Wrote survey questions and a survey template for SDSU professors to use in evaluating the impact of HPC reforms on the students in their courses. These resources are now available through the Education Center's website (www.edcenter.sdsu.edu).

5. The potential user base at SDSU and the current obstacles and challenges instructors face in bringing HPC into the classroom

LEAD's evaluation activities led us to several conclusions about the potential HPC user-base at universities like SDSU and the obstacles that professors face in incorporating HPC tools into their curricula. The most relevant of these conclusions for EOT-PACI as a whole are discussed in the seven sub-sections that follow.

5.1 Most professors have a lack of understanding about HPC technology and supercomputers and how either could be useful or relevant to their undergraduate curriculum.

In interviews with social scientists regarding why they don't do research using supercomputers or other high performance technology, Kiernan (1998) found that most of these scientists had a very limited notion of what supercomputers are used for or how they could contribute to social science research. Similarly, our evaluation found that most faculty members at SDSU have no conception of what high performance computing or "supercomputing" currently involves, much less how it could be integrated into their undergraduate curricula. In our faculty survey, over 75% of respondents said that they did not have "any knowledge of high performance computing or 'supercomputing' applications and how they may be used in the classroom." Not surprisingly, this differed markedly by college, with 90% of Arts & Letters respondents saying they had no such knowledge, as compared to 70% of Science respondents and 56% of Engineering respondents. When asked whether they saw themselves as having any use for high performance computing applications in their own courses, many faculty (35-40% per college) responded that they were unsure (see Table 1 below). On the other hand, 20% of Engineering respondents and 17.1% of Science respondents said they saw themselves as having a use for HPC tools in their courses, while only 3.1% of Art & Letters respondents said the same.

Table 1: % of SDSU faculty respondents by college who saw themselves as having a use for HPC applications in their courses.

HPC useful?	Arts & Letters	Engineering	Sciences	Total
No	61.5	40.0	43.9	50.0
Unsure	35.4	40.0	39.0	37.8
Yes	3.1	20.0	17.1	12.2

Our interviews with college deans, department chairs, and faculty who were trying to integrate HPC resources into their curricula further supported the notion that most SDSU faculty, and most university faculty in general, have a very limited conception of HPC technology and what it could be used for in instruction. The common conceptualization of supercomputers and high-performance computing applications is that they are nothing more than "number crunchers"—expensive and hard-to-access machines that are only of interest to physicists or theoretical mathematicians who need to perform millions of calculations with very large numbers and very complicated formulas. The typical response from researchers and instructors who have this conceptualization is: "Nothing I do in my research requires that kind of computing power. I can do all the calculations and demonstrations I want with my desktop PC." Our interviews, surveys, and reviews of the literature all suggested that few people associate HPC technology with its most relevant and pedagogically powerful application: as a means of constructing interactive models and visualizations that allow students to gain an intuitive grasp of scientific and mathematical principles and allow researchers to understand and explain the operations of complex systems. Until college faculty are better educated about HPC technology—both in terms of what it can do and in terms of how accessible it has become—few will have any notion of how it might be useful in their research, much less their teaching.

5.2 Most professors have too little time to learn about HPC technology or to develop a curriculum that utilizes it.

According to the literature on faculty resistance to instructional technology and LEAD's surveys and interviews of SDSU faculty, the number one obstacle that professors face in trying to bring computers and HPC tools into their curricula is a lack of time. Most professors, with the myriad of responsibilities they face in their research, their teaching, and on departmental and college-wide committees, have little or no time to learn how to use a complicated computer application, much less find a worthwhile role for that application in their curriculum. In our SDSU faculty survey, 31% of respondents listed a lack of time to learn about and develop computer-based curricular materials as their number one obstacle to using computers in instruction. This and a lack of convenient computer access (listed first by 27% of respondents) were the top two obstacles mentioned by far. In comparison, the third and fourth most common obstacles were a perceived lack of relevance to the coursework (listed by 5%) and a low level of student computer skills (listed by 5%).

This lack of time is the same problem faced by almost every type of instructional reform in higher education (Hutchinson & Huberman, 1993), but it is compounded in the case of HPC-based reforms because of the complexity and sophistication of the tools that have been developed thus far. Although the majority of the faculty at SDSU have at least some experience in using computers in instruction (see Tables 2-6 below), and this mirrors a trend towards greater computer competency and use in instruction among faculty nationwide (Campus Computing, 1998), there is a big difference between knowing how to search the Internet and being able to effectively use the frequently opaque HPC applications that one might find there. The fact is, using the currently-available HPC applications often requires even more technical skill than other forms of computer-based instruction. This means these applications generally take more time to learn, particularly if one has to program or otherwise adapt an application to meet one's instructional needs. Unless faculty members are offered buyout or have someone who can provide a high-degree of technical assistance, most faculty members, especially those still chasing tenure, are not in a position to spend a lot of time on HPC-based reforms. As one SDSU faculty member put it, "I think you will find that faculty often do not have the extra time to even come to training classes and then practice…If some technical assistants were available for, say 3-5 hours per week for one semester, you would see the computer literacy of faculty expand exponentially."

Table 2: Frequency of SmartClassroom use among SDSU faculty, by college

In % of respondents	College			
frequency of SmartClassroom use	Arts&Letters	Engineering	Sciences	Total
Never	47	36	36	40
Rarely	19	20	16	18

Sometimes	19	12	21	19
Often	16	32	26	23

Table 3: Frequency of student Internet use in SDSU faculty's courses, by college

In % of respondents	College			
frequency of student Internet use	Arts&Letters	Engineering	Sciences	Total
Never	33	55	48	43
Rarely	15	9	12	13
Sometimes	28	27	25	26
Often	25	9	15	18

Table 4: Frequency of having SDSU students use computers "hands-on" in the classroom, by college

In % of respondents	College			
freq of computer-based instruction	Arts&Letters	Engineering	Sciences	Total
Never	56	21	31	39
Rarely	21	25	12	17
Sometimes	11	38	23	21
Often	13	17	33	23

Table 5: Frequency of having students work with computer models in SDSU courses, by college

In % of respondents	College			
frequency of computer modeling	Arts&Letters	Engineering	Sciences	Total
Never	86	52	48	63
Rarely	7	13	19	13
Sometimes	7	13	17	13
Often	0	22	16	11

5.3 If professors are going to take the time to integrate HPC tools into their curricula, they need to be convinced that HPC applications allow them to teach concepts or processes in a more effective and sophisticated way.

A critical step in persuading professors to take the time for HPC-based curricular reforms is convincing them that HPC applications allow them to teach concepts or processes in ways that are more effective and more sophisticated than traditional methods of instruction. This is where demonstrations of the visualization and interactive modeling capabilities of HPC tools become essential. Not every discipline will have a clear need for HPC tools in undergraduate instruction, but it is important to expand faculty members awareness of the special things that these tools can do in some disciplinary contexts—things that instructors cannot do nearly as well on the chalkboard, the overhead, or even with other computer applications like spreadsheets, graphing programs, and Java applets. It is important to come up with potent examples of the unique and expansive abilities of HPC applications and to show professors how using these applications would give students a clearer and more intuitive grasp of fairly complex scientific principles. Reviews of the literature and our research at SDSU have suggested that any discipline which uses mathematical formulas to examine and understand the relationships in complex systems (e.g., biology, chemistry, physics, engineering, geology, forestry, psychology) can benefit from instructional tools that allow students to see, manipulate, and test hypotheses about these relationships using real-world data. The HPC applications that will be the most broadly used in the undergraduate curricula will be those that are relatively user-friendly but that provide students with virtual experiences and dynamic illustrations that go far beyond what a professor can otherwise produce in the classroom or lab.

5.4 Many professors still face limitations in the technical infrastructure and technical support needed to incorporate HPC into instruction.

Currently, the typical HPC application requires more advanced technical infrastructure and much more user support than most forms of computer-based instruction. Although universities are making progress in developing their technical infrastructure (Campus Computing, 1999), many still have an insufficient number of high-powered workstations or classroom computers with high-speed Internet access to make HPC-based reforms feasible. Even at a university like SDSU, which has a top-of-the-line (vBNS) Internet connection and a comparatively large number of Internet-equipped "Smart Classrooms," obtaining sufficient computer access for instruction is still a problem. In our faculty survey, lack of convenient computer access was the second most commonly mentioned obstacle to computer-based instruction. It was named as the number one obstacle by 18% of respondents from Art & Letters, 28% of respondents from Engineering, and 32% of respondents in the Sciences. (Note that these differences between colleges do not mean that Arts & Letters is the best equipped college, but rather that this college has less of a discrepancy between the degree of computer access and the degree of demand for computer-based instruction.)

An even greater problem is that the vast majority of universities lack the technical support staff to advise faculty who are interested in HPC applications. According to the latest Campus Computing survey (1998), most universities' technical support staffs are already overwhelmed with much less complicated calls for assistance—like how to use the Internet, how to program or use a Java applet, or how to set up an electronic collaboration environment for the students in one's courses. What's more, most universities' computer support staff do not themselves have the technical know-how to handle HPC-related inquiries, even if they had the time. If HPC-based reforms are to proceed, universities and interested investors will have to do a better job of funding the technical help needed to support faculty users of HPC. Alternatively, these tools could be made more user-friendly over time, allowing technical support to be less labor-intensive and more readily provided through national hotlines, email, or a university's regular technical support staff.

5.5 More professors would be encouraged to try HPC tools in instruction if the tools available were more user-friendly and better-attuned to their instructional needs.

Professors need instructional tools that are user-friendly and well-adapted to teaching the concepts of their discipline. This point should be obvious. A number of the department chairs we interviewed and faculty we surveyed expressed great interest in seeing examples of HPC tools that addressed the concepts they were trying to teach—examples that were relatively easy to use and fit well into their curricula. But most of these faculty came up empty-handed when they scoured the Web looking for such examples. Others were making do with Java applets and desktop applications they had programmed themselves and said they would consider moving to more advanced HPC applications only if these applications were as convenient to access and as simple to use.

5.6 Universities like SDSU have many faculty who would consider using HPC if they could overcome these obstacles, but also many faculty who do not believe in the use of computers in instruction.

SDSU, like many universities, has a large number of professors who have become interested in pursuing computer-based instruction (see Table 7 below). The two most prominent reasons for this, according to our survey and interviews, is that computer skills are seen as very important for students' futures and that computer applications, appropriately used, can assist in the learning of concepts. However, there are also a sizable number of professors who have only a passing interest in pursuing computer-based instruction—and not enough technical expertise to make such a pursuit attractive. Finally, all universities have a small but persistent core of faculty—particularly in the humanities, but also the more traditional faculty in mathematics and the sciences—who are staunchly opposed to the use of computers in instruction. According to our interviews with SDSU department chairs, these more traditional faculty are generally of the opinion that providing undergraduates with computer models or statistical programs allows them to bypass a critical step in the learning process: learning the mathematical and analytical foundations of a science. They want undergraduates to do things for themselves first, not have the computers "do it for them," and fear that working problems out on computers allows students to *think* they understand what's going on when they really don't.

Table 7: Degree of interest in computer-based instruction among SDSU faculty for three colleges

In % of respondents	College			
Degree of interest	Arts&Letters	Engineering	Sciences	Total
No interest	6	0	6	5
Small degree	20	0	8	11
Fair degree	38	48	38	40
Great degree	36	52	47	44

Experts in faculty change and pedagogical reform (Hutchinson & Huberman, 1993; NSF, 1996) have argued that reformers are only wasting their effort on this last group of faculty, who not only are disinclined to examine their pedagogical assumptions, but who actually believe a reform would be harmful. The best strategy for reformers is to focus on producing faculty models among the most enthusiastic and technically-advanced instructors while simultaneously reducing the obstacles for those who have some interest but lack incentive or technical know-how. This two-tiered strategy places most of the reformer's attention on those faculty who are the most capable of producing a curricular change that is lasting and worthwhile, while still devoting some attention to moving the more reluctant professors towards pursuing such reforms themselves.

5.7 Encouraging the incorporation of HPC tools into the undergraduate curriculum is a multi-tiered process which will require reformers to work with university administrators and department chairs as well as individual faculty.

Our review of the literature and our interviews with Faculty Fellows and department chairs made it clear that faculty cannot produce lasting change in the undergraduate curricula on their own. In most cases, they need not just the tolerance but the support of their department chairs, members of their faculty review committee, and the university administrators who provide the funds that make technology-based reforms possible. In short, a “systemic” approach to reform is needed. While individual faculty members remain the most important people to convince of the usefulness of HPC-based curricular reforms, their department chairs and their university administrators will also need some degree of convincing. Faculty members, especially untenured ones, need to know that they can pursue such time-consuming reforms without risking the disapproval of their departments, fellow faculty, and fellow researchers, for whom teaching is often considered a distraction from the more important work of one’s research (Foertsch et al., 1997; Hutchinson & Huberman, 1993). Although this is particularly true at large research universities and for untenured faculty, even tenured faculty reformers at universities like SDSU—which places a strong emphasis on the teaching of undergraduates—benefit from the tolerance and/or support of their institution.

6. An evaluation of the effectiveness of the strategies used by the Education Center to address the challenges to HPC-based instruction at SDSU

As is the case with any of the programs LEAD evaluates, our formative evaluation of the Education Center was designed to uncover which of the Center’s strategies were working well and which needed to be modified or improved. In our interaction with Education Center administrators, our interviews and surveys with current and potential Center clients, and our year-long observation of the Center’s numerous education and outreach activities, we learned a great deal about the role that an HPC resource center like SDSU’s Education Center can play in the integration of HPC-technology into the undergraduate curricula. In the seven sections that follow, we provide examples of the various ways in which the Education Center on Computational Science and Engineering is attempting to address the many obstacles that faculty members face in trying to incorporate HPC tools into their curricula.

6.1 How the Education Center educates faculty and students about HPC tools and supercomputing

One of the first and most basic roles of the Education Center is to inform faculty and students at SDSU about the relevance of HPC technology and supercomputers to their own lives and the potential roles these technologies could play in enriching their research and course curricula**.** Since so few people have a clear understanding of all the things that HPC applications currently make possible, the Education Center has had to spend much of its effort in its first two years of operation simply making people aware of HPC applications and the resources offered by the Center. This is accomplished through a number of means, including: the Center’s regularly updated webpage at www.edcenter.sdsu.edu, which includes links to other PACI sites and HPC resources; announcements and articles about the Center in SDSU or EOT-PACI publications; brief presentations regarding the services offered by the Education Center at departmental seminars and faculty meetings; and a program called NPACI Hours, where at the request of an interested instructor, Dr. Stewart or Dr. Zaslavsky gives an in-class presentation on supercomputing and, where possible, demonstrates discipline-specific HPC applications.

In just the first year of the Education Center's operation, these methods had already been reasonably effective in spreading the word about the Education Center and giving at least some SDSU faculty a better awareness of HPC technology and what it could be used for. In our faculty survey conducted in October of 1998, one year after the Education Center's opening, 28% of all respondents had knowledge of the Education Center, with the highest degree of awareness (40%) in the College of the Sciences, where Dr. Stewart had done the largest number of presentations and had the largest network of personal contacts (see Table 8). The means by which this information was gained can be seen for each college in Table 8, with personal contacts by Dr. Stewart and presentations by Education Center administrators being the most effective means by far, although all of the strategies reached at least some faculty members. Note that two important Education Center programs, NPACI Hours and the Faculty Fellows program, had only just begun at the time that this survey was conducted.

Table 8: How SDSU faculty received information about the Education Center, in number of faculty who recalled that source.

Source of information	Arts&Letters	Engineering	Sciences	Total
Personal contacts w/Dr. Stewart	6	1	21	28
Presentations by Ed Center	3	2	19	24
Email announcements	2	4	10	16
Deans/Department Chairs	2	0	13	15
Colleagues	1	2	10	13
News articles	2	0	6	8
Ed Center Website	1	0	7	8
Inquiry about Ed Center	1	0	5	6
Worked with Ed Center	0	0	5	5
Faculty Fellows Program	1	0	1	2
Faculty w/ Ed Center knowledge	(14%) 9	(28%) 7	(40%) 32	(28%) 49
Total faculty in sample	66	25	84	175

Our review of these various promotional strategies suggested that—as is the case with most reforms (Foertsch et al., 1997; Hutchinson & Huberman, 1993; Rogers, 1995)—personal and work-related contacts with Education Center administrators were the most effective way of persuading faculty to consider looking into HPC applications for their courses, although persistence was often required on the part of the Education Center administrators to bring faculty in for a closer look. Presentations at faculty meetings or departmental seminars were effective at making faculty aware of the Education Center and its mission, but few who attended were persuaded by these brief presentations alone to look further into HPC tools. Email announcements were more likely to hit their intended faculty target than were the numerous articles about the Education Center that appeared in various periodicals primarily read by SDSU students or partners in EOT-PACI—although spreading awareness of the Education Center among these other groups is also important. Finally, the Education Center website seemed more useful for people who had already heard about the Education Center through other means and were curious enough to pursue more information about it. Some faculty suggested that the website could do a better job of providing explanations of the HPC tools attached to the site and examples of *how* they might be integrated into one's curriculum.

6.2 How the Education Center provides professors with more time and more support to pursue HPC reforms

Since the primary obstacle to faculty members pursuing any type of curricular reform is a lack of time, it is essential that the promoters of HPC-based reforms come up with ways to free up potential reformers' time or to provide information and guidance that reduces the hours one would spend learning how to use HPC tools and devising curricular materials on one's own. Through the Faculty Fellows program, which debuted in the Fall of 1998, the Education Center attempts to do both.

Beginning in September of 1998, the Education Center began working with three SDSU faculty members who had competed for spots in the inaugural Faculty Fellows program. Each of these faculty members—a tenured male professor from Geology, an untenured male associate professor from Computer & Electrical Engineering, and an untenured female assistant professor from Geography—had applied for the Education Center's help in developing curricular materials that would use various forms of what they regarded as high-performance computer technology. In two of the three cases, the Education Center pushed the Fellows to go beyond what they had originally proposed to do so that the tools they were using came closer to the Education Center's and NPACI's definition of high-performance computing.

As compensation for the Fellows' efforts, the Education Center arranged 25% release time for each of them, half paid for by the Education Center and half by their College Deans. In most cases, this buyout of time will release an SDSU faculty member from one of the four courses they typically teach. Although all of the Fellows said that 25% of their time was far less than what it actually took to participate in the program and develop HPC materials for their courses, all agreed that providing at least *some* release time is an essential component of the program and is one of the primary incentives in getting faculty to participate. One Fellow didn't actually use his release time because there was no one who could take over the two courses he was teaching, and another would have proceeded with his proposed reforms—though at a slower pace—whether he participated in the program or not. However, all three Fellows and many of the department chairs we interviewed felt that most faculty could not even consider participating in such a labor-intensive program without the release time, and 25% of one's time, though insufficient to cover the actual amount of hours spent, was important as a symbolic gesture of support from one's college and one's department.

In addition to the release time, the Faculty Fellows program provides its Fellows with logistical, technical, and social support that speeds up the development of their curricular materials and makes it easier for them to access the human and technological resources they need to bring their projects to fruition. The Fellows are required to meet at the Education Center as a group every two weeks throughout the semester to share their experiences, brainstorm about how to solve certain technical or logistical problems they are having, and plan their projects' next steps. These regularly-scheduled meetings fostered the development of a "community" of faculty learners who were all interested in HPC and curricular reform. Through the Education Center and its associations with the San Diego Supercomputer Center, this community of Fellows was also connected to technicians and researchers at SDSU and the SDSC who could help them with technical problems and make sure that they had access to the technological resources they needed. For two of the Fellows involved—the two who wound up continuing their Fellowships through the Spring semester—the sense of community and support fostered by the program was one of its most important and rewarding aspects. As other LEAD evaluations have consistently demonstrated (Alexander et al, 1997; Courter & Millar, 1995; Foertsch, Daffinrud, & Alexander, 1998; Foertsch et al., 1997), reformers are much more likely to persist in their efforts and succeed in their reforms if they are surrounded and supported by a community of fellow reformers. Both of the continuing Fellows felt that such community is sorely lacking at large universities like SDSU, where faculty have few opportunities or venues to work or share ideas with faculty outside their discipline. One of these Fellows described the program as an engaging and productive "intellectual carpool" for faculty from diverse disciplines—faculty who otherwise never would have met:

> [People who come into this program] are interested in connecting to other people—like one of the other Faculty Fellows who is in networking, the person from Engineering—because the problems that we're trying to solve are problems that are not specific to our discipline…We've come to this program to connect to other people that know parts of how you solve those problems. Computer networking is a huge component of any solution of these problems, and so it's a really nice thing [to connect with someone in another department who's an expert in that]…Departments don't often connect. We park in different parking spaces, and we ding each other with our doors, but we don't interact. We have no carpools, in a sense. No intellectual carpools. And so this Faculty Fellows program, one part of it that I…really appreciate is that it's a very formal, specific means by which I can have access [to others' expertise] in a very, you could say, self-serving way. I can have access to somebody else's intellectual capabilities to try to help solve the same types of problems. The Fellow in Geography, she's very good at understanding how spatial representations of data are cognitively understood by the mind, and so her expertise is helping me to learn how you can take something and make a representation of it in a way that somebody can really understand it.

The importance of having ready access to HPC experts at the Education Center and the San Diego Supercomputer Center should also not be underestimated. As one Fellow explained:

> For me the Ed Center's role is [providing] an introduction to who are the right people to talk to at the Supercomputer Center…Who is the right person, and can you call for me so that they will actually see me?
>
> Interviewer: So it facilitates connections?
>
> Yeah. And also knowing other things that other people have tried to do…That's one of the things that [Education Center Researcher] Ilya Zaslavsky does very well. [Because he's taught distance ed courses using HPC]…he knows how a lot of these kinds of things might be done. It's good to have [someone with] the technical expertise to say, "What you are trying to do? Why don't you think about these kinds of ways of doing it," in a very gracious way instead of saying, "You can't,"…or saying, "I'll solve this for you," but instead, "This is how you can do this." Because I think most people don't want somebody to solve this for you. They want to help in how to figure this out, but still do it themselves because they're trying to learn it.

6.3 How the Education Center demonstrates the potential usefulness of HPC in the undergraduate curriculum

The Faculty Fellows program is also the primary means by which the Education Center demonstrates the powerful role that discipline-specific HPC applications can play in the undergraduate curriculum. The primary purpose of the program is to assist undergraduate instructors in adapting or producing HPC applications that are well-attuned to the needs of each instructor's curriculum. The ultimate goal of the program is to provide the campus and the nation with models for HPC-based undergraduate instruction—HPC applications that other faculty may use in their own courses *and* model faculty who can provide guidance to their peers on how to reap the benefits and avoid some of the difficulties of HPC-based instruction. The Fellow's program is at the heart of the Education Center's mission, and our evaluation found it to be the most effective of the Center's many strategies. Nevertheless, the Fellows program will not produce significant or lasting curricular changes in every case. From our observations, we predict there will be many Fellows who find an important niche for HPC applications in their curricula, but there will also be Fellows whose experiments with HPC do not go as intended or whose experience leads them to choose simpler, more traditional means of teaching the same concepts. The first year of the Faculty Fellows program exemplifies the wide array of outcomes that are possible for those who participate in curricular reform projects like these, as seen in the case studies described below:

<u>Case Study #1: Geological Sciences</u>—LEAD's first case study involved a tenured Geology professor who had been at SDSU for many years. He was seen as the ideal Faculty Fellow candidate by the Education Center because he was someone who was already familiar with HPC technology and had been thinking of ways to incorporate it into his curriculum. He hoped the support and expertise available through the Fellows program would help him "enhance" what he was already doing and "bring it to fruition more quickly." This Fellow proposed to create 3-D interactive visualization modules of highly-detailed full-color satellite scenes, something which requires the integration of massive amounts of data from several different sources. This kind of work cannot be done without the help of a supercomputer, but the applications themselves can be run off the Internet. The modules would be created in the Fall, to be used in two of his undergraduate Geology courses in the Spring. The purpose of these modules was to allow students to investigate complex geologic relationships and solve real-life problems regarding fault lines and resource management in geologically unstable regions around the world.

This professor proved to be the consummate ambassador for the cause of using HPC in the classroom for several reasons: First, he couldn't do what he wanted to do in his courses without supercomputers. Second, his HPC applications not only gave the coursework real-world relevance, but gave his geology students an edge in a technology that many of them will have to use in future jobs. Third, in every presentation he made to outside audiences, this Fellow made a point of emphasizing the necessity of supercomputers to his work and the pedagogical advantages of teaching undergraduates with dynamic HPC visualizations built from real-world data that make abstract disciplinary concepts immediately applicable to real-world problems. This Fellow seemed to gain more than anyone else from his participation in the Faculty Fellows program, and in every interview, he emphasized how important the community of Fellows and his collaboration with Education Center and SDSC researchers was in making his experience both productive and enjoyable. The modules he developed and piloted in his courses in the Spring of 1999 were excellent examples of how HPC-based applications can improve undergraduate education and become vehicles for lasting pedagogical reforms. Through the use of these HPC modules and the class projects in which they were embedded, this Fellow and his students transformed their classroom into an enthusiastic community of student researchers, collaborating in teams to solve real-world problems and gain technical skills that will give them a decided edge in their careers after graduation. This Fellow believed that it was his students, more than faculty members like himself, who would ultimately be the agents for change in the curriculum. In his interviews, he said that most faculty members are competitive and independent in the presence of their peers, and hence are more willing to learn from and adopt new technologies from their students than from other faculty.

<u>Case Study #2: Electrical and Computer Engineering</u>— The second case study involved a Computer Engineer who had been a visiting professor at SDSU for several years before gaining a tenure track position in 1999. Prior to the program, he had been involved in several distance education projects, and was currently teaching an advanced computer architecture class for electrical engineers. This professor had originally proposed to redesign one of his undergraduate courses as an on-line course using MATLAB, a high-tech collaboration tool available over the Internet. But Dr. Stewart needed someone to lead the way in making use of the College of Engineering's newly-acquired Network of Workstations (NOW)—an experimental high-powered system developed by researchers at Berkeley to run HPC applications like Virtual Reality—so she asked him to make programming on the NOW system a part of his course.

At Dr. Stewart's behest, this professor had five of his Fall honors students exploring the capacities of the NOW system's parallel programming architecture and figuring out its bugs. In the Spring, he continued to have two students working on NOW as independent study projects, but he returned to his work on collaborative tools with five other students, whose class project was to develop a Java-based Web-browser and whiteboard tool that could be used to teach distance education courses. At the end of the semester, the two students working on NOW presented their projects at the Electrical & Computer Engineering Department's weekly seminar, sharing with faculty and fellow students what they had learned about the NOW system and how it can be used. These two students will be joining Fellow #2's lab as research assistants in the summer and have become a potential resource for other faculty at SDSU interested in using the NOW system. Indeed, one of them will be applying to SDSU's graduate program next year and this Fellow is trying to get him NSF funding as a teaching assistant to "keep this resource in the department." As Fellow #2 explained, students with this sort of technical expertise are a valuable commodity and will be in great demand for other faculty in the department who want to learn how to effectively make use of NOW in their research and their courses.

Like the Fellow in Geology, one of things that Fellow #2 found most worthwhile about the Faculty Fellows program was the rare opportunity to interact with faculty from other disciplines who are interested in some of the same technical problems. Fellow #2 was an important resource on computer networking for the Fellow in Geology and now acts informally as a college-wide resource for people interested in using NOW.

<u>Case Study #3: Geography</u>—The third case study involved an untenured assistant professor from the Department of Geography, who only participated in the Fall semester of the program. Although her

research and the requirements of her field gave her a solid background in using computer visualizations in both research and instruction, the curricular reform she had originally planned did not meet the Education Center's criteria for a Fellowship-supported reform, primarily because it did not use supercomputing or HPC tools developed by PACI partners. She was planning on using the release time to modify one of her Geography courses to include instruction in customized programming for the computer visualization tool ArcView, a tool widely used by her field and in her department. The Geography department is one of the most advanced on campus in terms of its computer facilities and its push to incorporate computers into instruction, and many of its graduates will need to use computer programs like ArcView in their work. An interview the Geography Department's chair suggested that the department sees itself as self-sufficient and self-contained, with excellent computer facilities, its own discipline-specific computer applications, and its own computer support staff. While the chair was pleased that Fellow #3 was helping to develop a course that would provide geography students with valuable programming skills, he did not think the Education Center had much to offer the faculty in his department.

As a new faculty member still up for tenure, Fellow #3 seemed in a somewhat more vulnerable position than the other Fellows. Since her Fall course curricula had already been set by the time she received her Fellowship, it was agreed that instead of using the release time to work on her current programming course, she would spend the time finding a way to make use of on-line digital libraries and supercomputers in her later courses. When we first interviewed her in October of '98, she still had no idea how she was going to make use of the digital libraries for her research, much less her teaching. She and the Education Center had clearly different needs, but both sides were trying to find a way to accommodate each other. Fellow #3 received little practical help from going to the Faculty Fellows meetings because the discussions had little relevance to her current work or what she was capable of doing within her department in the near future.

However, this case study did provide a compelling example of how the Fellow's program and another Education Center program—NPACI Hours—can help raise students' and faculty's awareness of, and interest, in discipline-specific HPC applications. The Education Center worked with Fellow #3 for half of the semester just trying to come up with an HPC or digital library application that would be useful in a future Geography course. An Education Center student worker was assigned to this project, and halfway through the semester he succeeded in coming up with an HPC tool that geographers might find useful. Shortly thereafter, Dr. Stewart came in to Fellow #3's class for an NPACI Hours presentation in which she demonstrated the capacities of the new tool. She introduced a programming language that allows one to make 3-D visualizations out of things that are normally 2-D like ArcView. Fellow #3 was impressed by this demonstration and her students were too, but she wished it had come earlier in the semester. Nevertheless, the NPACI Hours demonstration gave a nice example of how the standard tools used in Geography could be enhanced by HPC, and as a result of that presentation, there were a number of Geography faculty who expressed interest in working with the Education Center in the future.

Stakeholders should know that producing "faculty models" through a program like the Faculty Fellows program is a slow and laborious process, but this does not mean it is not ultimately worth the effort. Currently, the Education Center works with three Faculty Fellows in any given semester, and some of those Fellows may need to extend their fellowship into a second semester in order to bring their projects to fruition. Considering all the potential barriers to HPC-based instruction that exist at most universities, convincing three to six faculty per year to use HPC applications in their courses may be the greatest rate of change that one could expect. But even a program that works directly with only a few faculty each year can still have indirect effects on a much larger group of faculty. Each "faculty model" provides the higher education community with another concrete and much-needed example of how HPC applications can positively impact the way disciplinary content is taught to undergraduates. In successful cases, Faculty Fellows become ambassadors for the potential of HPC within their departments, their colleges, and their disciplines.

6.4 How the Education Center works to improve the technical infrastructure at SDSU and make faculty aware of the technical resources available to them

At the very least, using HPC technology in instruction requires having access to classrooms or labs that have computers with high-speed Internet connections. Some of the most sophisticated HPC applications may even require the use of linked workstations like the Network of Workstations or submitting programs to supercomputers like those at the SDSC. Although universities like SDSU are gradually improving their technological infrastructure enough to make HPC-based instruction possible, this process requires educating college and departmental administrators about the growing importance of computer technology in research and instruction and the particular types of technology that are best suited to their needs. Some of the most advanced forms of technology are a "hard sell" unless administrators can be convinced that there is sufficient demand to make the investment worthwhile. One of the roles played by Education Center Director Kris Stewart is to act as an advocate for improving the technological infrastructure at SDSU and a consultant regarding the potential uses of various types of technology. As a Computer Scientist who attends a wide variety of technology and education-related conferences every year, Dr. Stewart is well positioned to learn about the latest technology and its potential applications in instruction. She then uses this knowledge to encourage SDSU administrators to acquire the technology necessary to keep the campus competitive with other universities in California and elsewhere.

Over the last three years, Dr. Stewart has been instrumental in bringing two technological advances to SDSU, both of which are important in supporting HPC-based instruction. The first is the National Science Foundation's (NSF) very-high-performance Backbone Network Service (vBNS), which allows scientists and engineers across the country to collaborate and share powerful computing and information resources. This very-high-speed Internet connection supports the next generation of the Internet (Internet 2) and provides the entire campus with smooth on-line access to the most sophisticated of HPC Web applications. The second technological advance the education Center helped their campus to acquire and promote is the experimental Network of Workstations (NOW), recently purchased by the College of Engineering. As described in Case Study #2, NOW supports the use of sophisticated HPC applications like virtual reality.

Dr. Stewart became involved with acquiring vBNS for SDSU when the Chancellor's Office sent out an announcement to SDSU faculty in July of 1997 asking for help in applying to the NSF for access to the vBNS line that links supercomputer centers and some research universities throughout the nation. If a number of projects at SDSU could make the case for needing vBNS access, it would make that opportunity available for the entire campus. Due to her work with the San Diego Supercomputer Center, Dr. Stewart understood the power that vBNS could provide to a campus, so she wrote a proposal describing how the Education Center would make use of vBNS and then volunteered to coordinate the effort for the campus. She and the Faculty Fellow from Geology, who also saw the usefulness of such access, worked to bring this opportunity to the attention of other people on campus who they thought might be interested. By the time they turned the proposal in to NSF in August, six separate SDSU projects had signed on to the effort. The proposal was accepted in February of 1998, and Dr. Stewart was named as the campus representative for meetings of the Corporation for Education Networks in California (CENIC), the governing group for vBNS networks in California. VBNS access became available to the SDSU in June of 1999.

Dr. Stewart's involvement in the College of Engineering's NOW project began in 1997 when the Dean of the College of Engineering asked for her help and advice in buying some Sun workstations and setting up an HPC network like the Berkeley NOW. Dr. Stewart contacted colleagues at the SDSC and asked them who she should consult with at UC-Berkeley in setting up such a system. In her subsequent conversations with Dave Cullers from Berkeley, she learned that the network connectors that SDSU's College of Engineering was purchasing would not allow them to use the same software as the Berkeley NOW, so she got them to change their order. In addition to providing this technical assistance, she acted as a liaison in getting Dr. Cullers to send some of his post-doctoral researchers to SDSU for the summer to assist in setting up SDSU's NOW. Then, when a professor from Electrical & Computer Engineering applied to become a Fellow, Dr. Stewart persuaded him to work with his students to explore the capacities of the NOW system and break the trail for other faculty who might have a use for it. As described in Case Study #2 (Section 6.2), that Fellow has now become a campus resource on NOW, as have two of his students who worked intensively on that system. Hence, Education Center Director Kris Stewart not only assisted SDSU's College of Engineering in setting up their NOW system, but has played a key role in promoting its use.

6.5 How the Education Center works to provide HPC-tools that are more user-friendly and better-adapted to an educational setting

Regardless of the intensity and breadth of one's outreach efforts, few faculty will be persuaded to use HPC applications in undergraduate instruction unless the tools available address real curricular needs and are not overly complicated to access or use. Recognizing this, the Education Center has made attempts to form working relationships with some of the NPACI Applications Technology (AT) and Enabling Technology (ET) teams who design and develop HPC tools. Until recently, the intended market for these tools did not extend beyond research scientists and corporations who were working in the computational area of their discipline, whether that discipline be Molecular Biology, Chemistry, Physics, Engineering, or Earth Systems Science. For non-experts, these tools can be very complicated to use, and the data visualizations they produce often require expert interpretation. If PACI wants these tools to be more broadly used, they will have to do a better job of producing user interfaces that are more straightforward and more streamlined, and that contain more interpretations and explanations to fill in the knowledge gaps of the non-expert user.

Refining the HPC tools in this way requires closer communication between tool developers and those familiar with the way that the tools will be used in the classroom. To that end, Education Center Director Kris Stewart has made regular attempts to communicate with members of NPACI's AT/ET teams at conferences, through phone calls and email, and through working collaborations. For example, when Dr. Stewart was invited to a Supercomputer Center meeting of NPACI's Earth Systems Science Thrust Area last fall, she became acquainted with an air quality visualization tool developed by Donald Dabdub of UC-Irvine. In talking afterwards, they both agreed it had the potential to be useful in undergraduate instruction, and they exchanged several emails exploring this possibility in the months that followed. Dr. Stewart met with Dr. Dabdub again at the NPACI All Hands meetings in January, where they agreed to proceed with a collaboration. But it wasn't until Dr. Stewart visited UC-Irvine in April that the collaboration really got started. She saw a demonstration of the tool and came back to SDSU with a copy of the necessary software. Dr. Dabdub is now working with the Education Center to help find an interested faculty member at SDSU, to demonstrate the tool to him or her, and to figure out how much the tool may need to be refined in order to be incorporated into the curriculum. This is precisely the degree of coordination that is required in order to make HPC applications suitable for classroom use. Unfortunately, attempts to communicate or establish working relationship with other PACI tool developers have not been as successful.

Then there is the problem of disciplines for which there seem to be few, if any, HPC applications. For example, as the article by Kiernan (1998) illustrates, most social scientists do not think HPC or supercomputing has anything to offer them, and in many cases, they are right—the tools that exist do not address their current research needs or interests. However, our survey of SDSU faculty showed that there were a significant number of faculty in the Psychology Department who were interested in computer-based instruction, and a few who thought that HPC applications could be useful in their courses. What tools, they asked, could the Education Center recommend? Since there were no tools in the PACI arsenal that addressed either psychology or social science statistics, the Education Center attempted to breach this gap by creating a tool of their own. As it happens, Education Center Staff Scientist Ilya Zaslavsky had spent several years helping to develop a Russian analytical software package called DAL Solutions, which uses Determinacy Analysis and Logic to extract rules (predictive patterns of association) from quantitative and/or qualitative data. This application allows social scientists to do convenient and powerful analyses of the relationships between various factors, even when some of the factors are non-numeric, something that standard statistical packages based on analysis-of-variance or the General Linear Model cannot do. During the 1998-99 school year, Dr. Zaslavsky modified and refined DAL Solutions to produce an application called the Sociology Workbench, a tool that allows social scientists to do determinacy analysis of their datasets over the Web.

Not all gaps in the HPC tool line-up are this large. For example, there is the case of the Faculty Fellow in Geography, who was having trouble coming up with a way to incorporate new HPC technology into her curriculum because her discipline already had a standard set of visualization tools that met her curricular needs. For cases like this, where a more powerful and dynamic version of existing tools must be located or designed, the Education Center employs undergraduate assistants, who scour the Web searching for appropriate tools, figure out the plusses and minuses of the tools that exist, and work on programming solutions when the tools they find prove inadequate. With the help of one such student assistant, Dr. Stewart found a way to program 3-D enhancements of the 2-D ArcView visualizations that the Fellow from Geography was using in her course. This was the HPC application that was eventually demonstrated for the Fellow's class during an NPACI Hours presentation.

6.6 How the Education Center targets its strategies to reach those faculty who are most likely to adopt HPC-based instruction

The Education Center on Computational Science and Engineering, like most campus technology centers, has limited staff and resources and can work with only so many faculty at once. Hence, their most labor-intensive strategies must target faculty who are the most likely to succeed in implementing HPC-based curricular reforms. The Education Center focuses most of their effort on programs like the Faculty Fellows program described in Sections 6.2-6.4, which works with faculty innovators who are already fairly committed to and capable of using HPC technology in undergraduate instruction. In late June of 1999, the Education Center will also host a workshop for faculty from California State University campuses who have expressed an interest in pursuing curriculum development using HPC applications. In preparation for this workshop, Center personnel are collecting modules that address applicants' expressed curricular interests. PACI partners nationwide have been invited to share the HPC education modules they have developed, in the hopes of encouraging further use of these modules and stimulating new ideas about the role that HPC applications could play in the undergraduate curricula.

The Education Center also makes an effort to educate faculty who might gradually develop an interest in HPC through the outreach and education strategies described in Section 6.1. However, our observations and our interview with Ethan Singer, SDSU's Associate Vice President for Academic Affairs, suggest that the Education Center could be doing more such outreach toward the campus as a whole. Although broader outreach efforts take a much longer time to produce measurable change in the undergraduate curricula, such efforts are necessary to germinate larger-scale interest in HPC technology and its uses in education. Vice President Singer said he would be very supportive of any efforts the Education Center made to educate the campus about HPC technology. He thought a week-long on-campus event like "Supercomputing Week" that had HPC-related demonstration booths, seminars, and open houses, would go a long way towards increasing the faculty and student body's awareness of and interest in HPC technology. After hearing such advice, the Education Center decided to hold an open house for incoming students and their parents. The first Education Center Open House was held in March of 1999 and was attended by a number of students interested in computer science.

6.7 How the Education Center works toward systemic changes at SDSU to create an environment that is more amenable for HPC-based instruction

From the beginning, Education Center administrators have understood that reform is a "systemic" process that requires reformers to enlist support at several different levels within a university's hierarchy. Faculty members who are interested in pursuing a reform like integrating HPC applications into their curricula will be unable to make much progress if they do not have the support, or at least the tolerance, of their department chairs, college deans, and faculty review committees—the people who decide how resources will be allocated and who will get tenure. Knowing this, Education Center Director Kris Stewart made a point of getting the support of university and college administrators right from the start, including Associate Vice President of Academic Affairs Ethan Singer, who approved the Center's funding. She met with the deans of the Colleges of Art & Letters, Engineering, and Sciences in order to make them aware of the Education Center and its mission and to persuade them to provide matching funds for the Faculty Fellowships she hoped to establish. She also gave a presentation about the Education Center at a meeting of the College of Science's department chairs, and made phone calls to the chairs of departments in which Faculty Fellows would be working in order to solicit their support for the Fellows program and other activities of the Center. The two Fellows who remained in the program for both semesters said that having financial support from their college deans and the implicit or explicit approval of their chairs helped greatly to reduce the degree of risk they faced in taking the time to pursue HPC-based reforms. By contrast, in the case of the Geography professor who did not continue on, the skepticism of her department added to her concerns about participating in the program. At the time of our interview, her department chair was unconvinced of the of the relevance of the Education Center or the HPC-based tools they were suggesting to his department's needs. This uncertainty and the need to justify the time taken from research was clearly on the Geography Fellow's mind during our first interview.

In addition to making it less risky for faculty to participate in HPC-based reforms, the Education Center needs the support of university administrators if it is to succeed in its goal of reforming the undergraduate curriculum at SDSU. Part of the Education Center's funding comes from SDSU through the Office of Academic Affairs, while the rest comes from the NPACI/SDSC branch of EOT-PACI and from the California State University System. This funding structure assures that the Center is officially sanctioned by the university it serves. It also means that the Education Center has a responsibility to all three of its funders and must balance the needs of these separate organizations in all that it does. Throughout the year, Education Center personnel and the Faculty Fellows they support have been required to report on their progress and give demonstrations of their HPC tools to stakeholders. If the Education Center proves successful in its goal of incorporating PACI's HPC-applications into SDSU's undergraduate curriculum, they can serve as a model for a similar education center that would serve the needs of the entire California State University system. If this occurs, the reforms begun at SDSU's Education Center will become "systemic" in several senses of the word.

7. Changes in the Education Center's strategies brought about through evaluation

Over the course of our one-year evaluation of SDSU's Education Center on Computational Science and Engineering, the LEAD research team learned a number of ways in which the Education Center's strategies could be refined and improved. This information was passed on to Education Center administrators informally through emails and teleconferences, and more formally through reports and formative feedback meetings throughout the year. The benefit of a formative evaluation such as this one is that it allows program administrators to refine their strategies and even their goals as soon as it is deemed useful or necessary to do so. In the case of the Education Center, some changes have already been prompted by LEAD's evaluation feedback. The Education Center made the following refinements to their strategies before our year of evaluation was even complete:

- The data from LEAD's faculty survey allowed the Education Center to identify the SDSU departments that were the most amenable to HPC-based reforms. The Center has since focused their efforts on these more fertile departments and the faculty within them that had expressed an interest in HPC technology. The seven departments whose faculty showed the greatest degree of interest in computer-based instruction and HPC-based reforms are: Biology, Chemistry, Electrical & Computer Engineering, Geological Sciences, Mathematical & Computer Science, Mechanical Engineering, and Psychology. The Education Center has already begun contacting interested faculty and working with curricular reform groups within some of these departments.

- After our interviews and literature review established the importance of evaluation data in persuading faculty of the usefulness of HPC-based reforms, the Education Center asked for our help in developing and evaluation instruments that their Faculty Fellows and other faculty reformers could use to measure the impact of their HPC-based curricular reforms. LEAD developed questions and a survey template from which faculty could construct their own course surveys and evaluation forms. These materials are now available to all faculty through the Education Center's website.

- All of our evaluation data suggested that reforms are most effectively spread through disciplinary insiders who have themselves tried the reform in question. While Dr. Stewart, a computer scientist, can make effective presentations to inform people about the Education Center and HPC in general, we have learned that demonstrations of discipline-specific HPC applications are best done by faculty who are disciplinary insiders—people whose research is familiar to those they are trying to persuade and who know the content and the complexities of a course or discipline well enough to answer whatever questions or concerns that arise. This feedback has made the Education Center realize all the more the importance of using the Faculty Fellows as ambassadors for HPC-based reforms. Within their own disciplines, the Fellows are far more effective mouthpieces than a computer scientist or any other disciplinary outsider can be. Dr. Stewart now has the Faculty Fellows argue the case for HPC-based reforms whenever possible, including in presentations to SDSU and California State University administrators.

- After hearing that Associate Vice President Singer felt they should be doing more outreach activities to impact the campus as a whole, and after learning that students can be effective agents for curricular change, the Education Center instituted an Open House for incoming students in March. Next year, they will institute another new program to work directly with students called the Computational Science Olympics, a campus-wide competition where SDSU undergraduates will design, implement, and report on computer projects that use HPC technology. It is hoped that faculty will be impressed and intrigued by the HPC computer applications that their undergraduates are able to produce.

8. Concluding lessons for PACI in how to facilitate the use of HPC technology in the undergraduate curriculum

The first goal of LEAD's evaluation of the Education Center on Computational Science and Engineering was to provide formative feedback to Education Center administrators on the Center's progress in achieving its goals and recommend ways to make the Center more effective and more efficient in achieving those goals. LEAD's feedback and recommendations for improvement were passed on to Education Center administrators throughout the year and have been summarized in this report. The second goal of LEAD's evaluation was to provide year-end summative feedback that would enable Center personnel, stakeholders, and funders to see how effective the Education Center had been in its second year of operation and to share the lessons learned about how to best encourage the incorporation of HPC applications into the undergraduate curriculum. Our findings suggest that, with proper guidance and continual assessment of their progress, HPC resource centers like the Education Center can be effective in encouraging significant change in the undergraduate curriculum in the long run. However, as with any reform, stakeholders must be patient and allow such programs the time to establish themselves and learn what strategies work best for their given context. The Education Center's most intensive and effective strategies—like the Faculty Fellows program—will impact fairly small numbers of faculty initially, but over time, the participants in these programs will become models for change and encourage an even greater number of faculty to follow in their footsteps.

However, the fact remains that centers like SDSU's Education Center cannot persuade large numbers of faculty to try HPC-based instruction until PACI's tool developers come up with more user-friendly HPC tools that are better adapted to the needs of undergraduate instructors. Tool developers like NPACI's AT/ET teams and tool promoters like the Education Center have to work *together* to find ways of learning about and meeting the needs of undergraduate instructors. If PACI wants to increase its user base, the onus is on AT/ET teams to: (1) find out how existing HPC tools can be adapted for instructional use, or (2) discover what instructors needs are and develop tools that take these needs into account right from the start. The Education Center and other members of EOT-PACI's Undergraduate Team can assist the AT/ET teams in this undertaking, but they cannot do it on their own. Encouraging college instructors or any other potential user group to find a meaningful role for HPC applications in their work is a complicated undertaking that requires the cooperation and collaboration of all areas of the Partnership.

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Appendix A: Survey of SDSU Faculty's Current Information Technology Needs and Practices
Fall, 1998

Conducted by the LEAD Center for the Education Center for Computational Science and Engineering with the cooperation of the Dean's Office. Your participation is critical to the College obtaining an accurate assessment of your needs.

Please return this survey by FRIDAY SEPTEMBER 25!!

(1) What is your gender?
___(a) Male
___(b) Female

(2) In which College are you appointed?
___(a) Arts and Letters
___(b) Business Administration
___(c) Education
___(d) Engineering
___(e) Health and Human Services
___(f) Professional Studies and Fine Arts
___(g) Sciences

(3) In which Academic Department are you appointed?:

(4) How many years have you been teaching at the university level?:

(5) Do you have tenure?
___(a) Yes
___(b) No

(6) How frequently do you use each of the following computer applications? Use this scale to indicate the approximate frequency:
0=never;
1=a few times a year;
2=monthly;
3=weekly;
4=daily;
___(a) E-mail, such as Eudora
___(b) Electronic presentation programs, such as PowerPoint
___(c) The Internet or World Wide Web
___(d) Electronic indexes (like ERIC, Dissertation Abstracts, etc.) that are stored on CD-ROMs or on the Internet
___(e) Interactive models or data visualization applications available over the Internet
___(f) "Digital libraries" (containing large datasets that may be used by anyone) on the Internet

(7) What is your approximate level of skill for each the following computer-related activities? Use this scale:
0=I have never tried this
1=I have only the most basic skills
2=I am fairly skilled
3=I am highly skilled

___(a) Finding materials and information on the Internet
___(b) Using interactive models or data visualization programs on the Internet
___(c) Creating electronic presentations using programs like PowerPoint
___(d) Creating Web pages or other materials for the Internet
___(e) Creating or adapting interactive computer materials for use in instruction

(8) How much more skill would you *like to have* in these areas? Use this scale to rate how interested you would be in increasing your skills:
1=I am not interested in gaining more skills
2=I would like to add to my skills in some areas
3=I would like to be much more skilled

___(a) Finding materials and information on the Internet
___(b) Using interactive models or data visualization programs on the Internet
___(c) Creating electronic presentations using programs like PowerPoint
___(d) Creating Web pages or other materials for the Internet
___(e) Creating or adapting interactive computer materials for use in instruction

(9) How many undergraduate courses do you teach in a typical semester?:

(10) Have you ever created a World Wide Web page for your courses?
___(a) Yes
___(b) No

(11) While teaching at SDSU, how often have you used a "smart classroom" (equipped with a computer presentation system) or brought a computer to your classroom to present information to your students?
___(a) Never (skip Q11b)
___(b) Rarely
___(c) Sometimes
___(d) Often

(11b) How many of these computer presentations involved use of the Internet?
___(a) None of them
___(b) Some of them
___(c) Most of them
___(d) All of them

(12) While teaching at SDSU, how often have you had your students use computers in the classroom, “hands-on,” as part of the regular in-class curriculum?
___(a) Never
___(b) Rarely
___(c) Sometimes
___(d) Often

(13) In a typical course in the last *two years*, how often have you required your students to engage in the following computer-related activities? Use this scale to rate the frequency:
0=Never;
1=Rarely;
2=Sometimes;
3=Often;
___(a) Obtain course materials/information from my course Webpage
___(b) Retrieve information from the Internet for class assignments
___(g) Interact with classmates about class assignments via a computer
___(d) Use interactive computer models or demonstrations to learn a concept
___(b) Use computers to analyze data or do computation
___(a) Learn how to program computers

(14) What degree of *interest* do you have in using computers in instruction?
___(a) I am completely opposed to it
___(b) Absolutely no interest, though I am not opposed to it in principle
___(c) A small degree of interest
___(d) A fair degree of interest
___(e) A great degree of interest

(15) What do you feel is the *greatest obstacle* to you using computers in the instruction of your students?

(16) What would you see as the *greatest benefit,* if any, to using computers in the instruction of your students?

(17) Do you have any knowledge of high performance computing or “Supercomputer” applications and how they may be used in the classroom?
___(a) Yes
___(b) No

(18) Do you see yourself as having any use for high-performance computing or “Supercomputer” applications in your own courses?
___(a) Yes
___(b) No
___(c) I am unsure

If *Yes*, for what purpose?:

(19) How familiar are you with the San Diego Supercomputer Center?
___(a) I'd never heard of it before now
___(b) I'd heard of it before now but know little or nothing about it
___(c) I have a basic knowledge about it and its purpose
___(d) I am very familiar with the Supercomputer Center and its purpose

(20) How familiar are you with the Education Center for Computational Science and Engineering on the SDSU Campus?
___(a) I'd never heard of it before now
___(b) I'd heard of it before now but know little or nothing about it
___(c) I have a basic knowledge about it and its purpose
___(d) I am very familiar with the Education Center and its purpose

(21) How did you become informed about the Education Center? Check all that apply:
___(a) I have no information about it
___(b) Through on-campus fliers or announcements
___(c) Through newspaper or magazine articles about the Center
___(d) Through the College Dean or my department chair
___(e) Through colleagues on campus who have used or considered using it
___(f) Through personal contacts with Center staff
___(g) Through faculty presentations or workshops given by Center staff
___(h) Through participation in the Center's "NPACI hours"
___(i) Through the Center's Faculty Fellows program
___(j) Through the Center's Website
___(k) I have inquired about the services the Center provides
___(l) I have worked or consulted with Center staff regarding my courses

(22) How useful do you see the Education Center as being in regards to your own needs and plans as an instructor?
___(a) I do not know enough to answer
___(b) Not very useful
___(c) Somewhat useful
___(d) Very useful

(23) What do you perceive as your greatest need in the area of computers and technology?:

Appendix B: SDSU Deans Interview Protocol

1. What are your views on the value of integrating high performance computing tools into the undergraduate curriculum at SDSU?

2. What is the role of the university administration in [bringing about] the incorporation of high performance computing tools in the undergrad curriculum?

3. What do see as the major barriers to faculty using high performance computing tools in teaching?

4. What do you think will convince faculty to use this type of tech as part of their curriculum? What is the process? What do you think is the process of change at a university such as SDSU? (gets at local factors as well as their conception of the process of encouraging faculty to utilize these HP tools as part of undergrad curriculum).

5. Question about "equipment"/resources ("technical parameters of computers and networks") and university computing policy. See section 2.10 Grand Challenges.

6. What do you think the role of the Ed Center is at SDSU?

7. Faculty Fellows Program: their view of this program, basically why they are supporting it

8. What department chairs would you recommend that we talk to about these issues?

Appendix C: SDSU Department Chairs Interview Protocol (Used in October interviews)

1. How long have you been at San Diego State? How long have you been department chair?

2. What is your teaching load as department chair? What courses do you teach?

3. Do you use computers for instruction in any of your courses? How so?

4. What are your views about computer technology and the role it should play in higher education? [How did you come by that view?]

5. What are your views on the value of integrating high performance computer technologies/applications into the undergraduate curriculum at SDSU? [visualization and modeling tools and interactive visualization, use of large data sets]

6. To what degree do you feel your department has the infrastructure to incorporate high performance computer technology into their curriculums?

7. To what degree do you think the faculty in your department have an interest in using computers in instruction? Why or why not? [What do you know about their feelings about using computers in instruction and how do you know it?]

8. Is it a goal for your department to incorporate the use of computers and computer technology into the curriculum? Do you have a long range plan? What do you think the time frame is for meeting your goals?

9. What do you think will motivate faculty in your department or your discipline to use high performance computing technology as part of their curriculum? [What is the process?]

10. What do see as the major barriers to faculty in your department or discipline using high performance computing applications in their teaching?

11. What do you know about the Education Center on Computational Science and Engineering here at SDSU? Explain the Education Center and its mission if they don't already know about it.

12. How did you become informed about the Education Center?

13. What do you see the role of the Education Center as being with regard to your own department?

14. What would the faculty in your department want most from a campus service like the Education Center?

15. For your department, what would be the best way to inform faculty about high performance computing tools and to encourage their use in the undergraduate curriculum?

16. Have you heard about the Education Center's Faculty Fellows program/ NPACI hours? Explain what they are if they don't know.

17. Would something like the Faculty Fellows program/ NPACI hours be useful for the faculty in your department? How?

18. Do you think the faculty in your department would be interested in participating in something like the Faculty Fellows/NPACI hours program? Why or why not? [What might work better for them?]