Expectations for a Scientific Collaboratory: A Case Study

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ABSTRACT
In the past decade, a number of scientific collaboratories have emerged, yet adoption of scientific collaboratories remains limited. Meeting expectations is one factor that influences adoption of innovations, including scientific collaboratories. This paper investigates expectations scientists have with respect to scientific collaboratories. Interviews were conducted with 17 scientists who work in a variety of settings and have a range of experience conducting and managing scientific research. Results indicate that scientists expect a collaboratory to: support their strategic plans; facilitate management of the scientific process; have a positive or neutral impact on scientific outcomes; provide advantages and disadvantages for scientific task execution; and provide personal conveniences when collaborating across distances. These results both confirm existing knowledge and raise new issues for the design and evaluation of collaboratories.

Categories and Subject Descriptors
K.4.3 [Computers and Society]: Organizational Impacts - *Computer-supported collaborative work*; J.2 [Computer Applications]: Physical sciences and engineering - *Physics; Chemistry*

General Terms: Management, Design, Human Factors

Keywords
Collaboratory, scientific collaboration, expectations, adoption, interviews

1. INTRODUCTION
The scientific collaboratory concept promotes the vision of scientists using advanced, multi-media information and communications technology to have increased access to scientific instruments and tools, data and experiment results, as well as other scientists across geographic distances and time [4, 10, 19]. A number of scientific collaboratories have emerged, with varying degrees of longevity and use. Finholt [3] and Kouzes [7] provide a comprehensive description of existing scientific collaboratories. For example, from 1992 to 2000, financial budgets for scientific research and development (R&D) collaboratories ranged from $447,000 to $10,890,000 and total use ranged from 17 to 215 users per collaboratory[1] [3]. These statistics call into question whether scientific collaboratories meet scientists' expectations, and what criteria should be used when designing and evaluating a collaboratory.

Adoption of innovations, including scientific collaboratories, is to a large extent about meeting expectations. If an innovation does not meet, or exceed, an individual's or group's expectations, they may chose not to use the innovation. Expectations may be based on perceived breakdowns or limitations with current, existing practices [18], compatibility with current practices and norms [12], and advantages over current practices [5, 12, 17]. This paper investigates expectations scientists have with respect to scientific collaboratories, in order to provide insights regarding the adoption, design and evaluation of scientific collaboratories.

To discover scientists' expectations, semi-structured interviews were conducted with 17 scientists who had indicated a willingness to participate in the design and evaluation of a new scientific collaboratory. The scientists work in a variety of settings, including a research university, national research lab and industrial R&D lab, and they have a variety of experience levels, ranging from student to senior scientific management. Like many scientists, they participate in face-to-face and geographically distributed scientific collaborations and, at the time of the interviews, did not have first-hand experience with a scientific collaboratory.

Results indicate that scientists expect a collaboratory to: support their strategic plans; facilitate management of the scientific process; have a positive or neutral impact on scientific outcomes; provide advantages and disadvantages for scientific task execution; and provide personal conveniences when collaborating across distances. These results both confirm existing knowledge and raise new issues for the design, evaluation and adoption of scientific collaboratories. How should we design collaboratories to facilitate organizational growth, scientific career growth and the process of science to address scientists' expectations? How should we evaluate collaboratories based on these measures of success, which are by nature long-term and influenced by other variables?

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[1] These statistics do not include collaboratories that are primarily focused on scientific education.

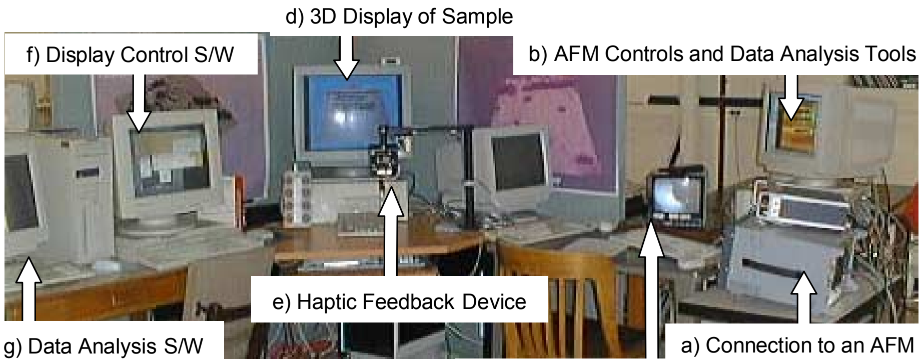

Figure 1. Stand-alone, single-user nanoManipulator (nM)

2. RESEARCH METHODOLOGY

2.1 Study Participants

The study participants were scientists working in a variety of settings, including a research university, national research lab and industrial R&D lab. They had a variety of experience levels, ranging from student to senior scientific management. The participants included two department and project managers at a national research laboratory, four faculty, one postdoctoral fellow and four graduate students in three natural science departments at a major, public research and doctoral granting university, two faculty and one graduate student in computer science at the same university, two visiting science students from major research universities, and a scientist who founded a biotechnology company. Thus, the scientists worked in a variety of settings and they had a variety of experience levels.

Each participant was familiar to varying degrees with the stand-alone, single-user version of the scientific instrument that was to basis of the new scientific collaboratory. Six natural scientists had used the instrument, or supervised students who used the instrument, extensively for six to twelve months; four had used it for several days to conduct specific experiments; and four had only seen demonstrations of the system. The computer science faculty and student were involved in the development of the stand-alone instrument. Each participant was actively collaborating with at least one other participant at the time of the interviews, and they anticipated the collaboration would continue for some time. The collaborations included, in part, the use of a nanoManipulator, a specialized scientific instrument (see below), initially the stand-alone version and potentially the collaboratory version. All participants were knowledgeable about state-of-the-art information and communications technology, e.g., the Internet, and the collaboratory concept. They were also experts and leaders in their area of scientific expertise, actively publishing papers, filing for patents, leading and participating in international conferences and national scientific advisory boards. All had experience participating in face-to-face and geographically distributed collaborative research.

2.2 Collaboratory System

The collaboratory system under development was to provide distributed, collaborative access to a specialized scientific instrument called a nanoManipulator (nM). The nanoManipulator (nM) instrument provides a natural scientist with the ability to interact directly with physical samples ranging in size from DNA to cells. It incorporates visualization and haptic technology to allow scientists to see, feel, and modify biological samples being studied with an atomic force microscope. As illustrated in Figure 1, components of the stand-alone, single-user nM instrument include: (a) connection to an atomic force microscope (AFM) that scans samples on the nanometer scale; (b) personal computer (PC) based AFM controls and data analysis tools; (c) video display of the sample in the microscope taken by a camera in the AFM; (d) 3D graphics display of a virtual model of the data collected by the AFM; (e) software controls for the virtual environment system, including the 3D graphics display, AFM and haptic feedback device; (f) the haptic feedback device that allows users to feel a sample; and (g) PC based data analysis software tools. Figure 2 provides an example of the graphical output from the nM. Details regarding the nM and its uses are described in [2, 6, 15].

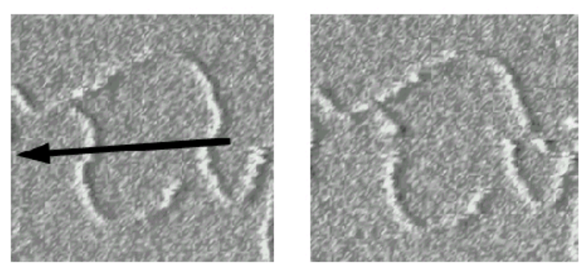

Figure 2. Sample output from nM: Visualization and manipulation of DNA[2] (Guthold, et al, 1999)

[2] The arrow represents the movement of the microscope tip manipulating the DNA.

2.3 Interview Data Collection and Analysis

The semi-structured interviews were part of a larger study to learn about the collaboration process in science and to develop design requirements for the collaboratory system [14]. During the interviews, scientists were also asked about their expectations regarding the proposed collaboratory. What advantages did they anticipate the collaboratory would, or could, provide? How might the collaboratory impact their work? Why were they interested in using the collaboratory system?

Each scientist participated in at least one interview, ranging in length from 60 to 120 minutes. Several scientists volunteered to participate in additional interviews to share additional experiences regarding scientific collaboration and/or use of the stand-alone nM. Each interview was recorded and later transcribed. A total of 21 interview transcripts were analyzed for this paper.

The interview data were analyzed using both open and axial coding [1]. During open coding, each interview was read thoroughly and carefully to identify those segments focusing on expectations regarding relative advantages. The segments were further analyzed to identify major themes, or coding categories, regarding relative advantages. The segments were re-read to determine whether additional themes emerged and/or themes should be merged into one category. During axial coding, all segments were re-read and analyzed using the themes as coding categories.

3. RESULTS

Data analysis revealed that scientists' expectations encompass five categories: strategic plans, management of the scientific process, scientific outcomes, experiment tasks and personal convenience. Not every participant mentioned each category. Senior scientists mentioned strategic plans more frequently than graduate students, and graduate students and postdoctoral fellows mentioned experiment task execution more frequently than senior scientists. However, no category can be attributed solely to any one particular seniority level or work context. Details regarding each type of expectation are discussed below.

3.1 Expectations with respect to Strategic Plans

Surprisingly, study participants mentioned expectations with regards to strategic plans most frequently. Eight (out of 17) participants discussed how they expected the collaboratory could support long-range goals that were part of their strategic plans. For example, one scientist commented:

> *The experiments may or may not work, but even if the experiments themselves aren't all that informative, [the collaboratory] will be very valuable in the sense of establishing closer working relationships with the people [at the university] which is something this institute is very, very interested in doing…To the extent that you can leverage your influence and your dollars by...strategic partnerships, everybody benefits…[A scientist using the nM at the university] thinks very differently than I do…[and] that may be even more important than the infrastructure is. Interaction with [such people at the university] complements my own deficiencies...and they say something that changes the way I think. That's extremely important.*

For this scientist, the strategic relationship with other institutions and other scientists that are afforded by partnership within the collaboratory are more important than outcomes of the planned scientific experiments. If the experiments conducted using the collaboratory system produce good outcomes that would be fine, but more important are the relationships the collaboratory enables.

This perception is echoed by another scientist who said:

> *[The nM] is really a tool of collaboration…There's project-oriented science and then there's technique-oriented science. [The nM collaboratory] is more of a technique-oriented science. I have a technique that I can do very cool things with, and so …I'll apply it to multiple [biological] systems...So, in part, it's the technique that requires [collaboration]…and in part, I just like to collaborate with people…You get more ideas and more knowledge, and you'll get to do things that you might otherwise not do.*

Another scientist expressed the opinion that the collaboratory was a vehicle to establish a scientific center at the university. The scientist reported:

> *We're clearly interested in applying [the nM instrument] to a wide range of problems…and we could apply for these other moneys…You can see how [another scientist] got involved because it's an interesting network problem…and it's an interesting science study problem. It's an interesting outreach project. So it's got all these aspects to it which when you put them together become a fantastic group of activities to bundle together into a center.*

In addition to supporting the creation of a center, another scientist discussed the possibility of the collaboratory system helping to open a new branch of science:

> *More than contributing to research that we are already doing, [the collaboration using the nM instrument] is opening up a new branch [of science] for us…I see it as a really exploratory kind of pursuit…I see it as a new door for me and for the lab, and not something that exactly contributes to what we're doing now…[but] that is an entirely new kind of field.*

Several collaboratories, e.g., Chickscope and Bugscope [16], have been established to provide K-12 students opportunities to use remote scientific instruments, and the issue of using collaboratories to provide access to specialized scientific instruments has also been discussed in the literature (e.g., [3]). Similarly, two study participants (graduate students) also mentioned outreach to high schools as well as smaller universities and colleges was potential advantages for the collaboratory.

> *Working in a distributed fashion would allow students and scientists that don't have a great deal of resources to do…interesting work…If the technology was concentrated at different locations across the country, I would be worried that the little guy might be left out…I think it's important to expose high school students to [state-of-the-art scientific instruments.]*

Another student contrasted the development of the collaboratory with the establishment of a start-up company to sell the nM. The student suggested that establishing the collaboratory was an effective way to get more people using the system, suggesting new features and conducting new scientific experiments:

> *until such time the nM [can] become a start-up company.*

Thus, the collaboratory was seen as a means to establish a customer base for a subsequent start-up company that would sell the instrument.

In summary, many scientists looked to the collaboratory as a means to achieve strategic goals that were organizational and personal in nature. These goals included: establishing relationships with other scientists who had specialized knowledge and could increase one's own knowledge and activities; creating a research center; developing a new branch of science for professional and organizational growth; providing scientific opportunities for high school students and others; and, expanding the utility and use of the scientific instrument for subsequent commercial purposes.

3.2 Expectations with respect to Management of the Scientific Process

Six (out of seventeen) scientists mentioned that they expected the collaboratory to impact the scientific process. In particular, they anticipated that the opportunities for collaboration afforded by the collaboratory system would help eliminate the long periods of inactivity commonly found in scientific collaborations that occur across geographic distances. As one scientist commented:

> *Most…collaborations that I've had work in spurts where you have a specific project in mind and really…[put your] energy into that specific thing. Once that's over with, ...the collaboration typically peters out. Well, that could be overcome with more discussion and devices for hypotheses building…to be able to overcome these peaks and valleys would be a big factor…to extend the collaboration beyond the intellectual concept that was developed…when the collaboration started…So that intellectual concepts are developed within the collaboration, so the second and third generation experiments will come from the collaboration…that's a big need…This remote experimentation idea is one approach to doing that*

The collaboratory was also viewed as a vehicle for team building and recruiting graduate students and other scientists:

> *At the top of the list [of anticipated benefits] is team-building...[and] attracting people who would be interested in working on [the natural science] project…I think [the collaboratory system will] payoff in the long-term for reasons of team-building and improved communication [among collaborators.]*

Other scientists mentioned that they anticipated the scientific process would speed up when they had access to the nM collaboratory. When collaborating across distances, scientists may not share their data until they believe the data are worth sharing. However, insignificant data to one scientist may be very significant to another scientist, especially when the scientists come from different disciplines. Two scientists who were collaborating with scientists from a different discipline reported:

> *I think progress [currently on this project] is definitely slow…it's a little frustrating…there's a tendency [for collaborators] to only bring data [to us] that looks interesting…And so very often, I don't see the data that might not look interesting to [my collaborators] but to me says …something about what we're doing and how we're doing it. Very often looking at your mistakes more closely can tell you which way to go. I think getting a…live hook-up is going to help...really add to our interaction.*

> *If you're actually experiencing or having the opportunity to participate [in an experiment], you clearly add different types of insight versus where it's communicated to you or someone shows you something and you're trying to decide how was it done and what were they doing and things like that…We inherently use different languages because the disciplines we are in, are in different worlds and so [participating in an experiment] would reduce the barriers we have in communicating…So when we can sit down together and [conduct experiments], things will move very rapidly…The project will probably take on a new life.*

The scientific process was also expected to be shortened through a reduction in the number of errors during experiments and the subsequent associated repetitions of an experiment.[3] A scientist explained:

> *The advantage of the [nM collaboratory system] will really be in experiencing, or kind of directing, the experiment…as it's taking place... If you see something is either not going the way you had expected, it gives you a chance to intercede. If you see that suddenly you observe something interesting, that gives you a chance to pursue it without having to set up a whole new experiment.*

In summary, expectations with respect to management of the scientific process reported by scientists include elimination of periods of inactivity, team-building, and new opportunities to direct experiments and subsequently increase interaction and pace.

3.3 Expectations with respect to Scientific Outcomes

Somewhat surprisingly, few scientists expressed the expectation that the collaboratory would provide advantages related to scientific outcomes. Scientists commented:

> *I see [the collaboratory] as a vehicle for promoting interaction more than as a way of getting data collected more robustly…My view of it is more as a facilitating device as opposed to a primary data collection device.*

> *The impact nanomanipulation will have on my research…in the short term is minimal…[The experiments we plan to conduct] may or may not work...but they may be very informative, it's not that I'm not excited about it, we'll just have to see.*

However, some did expect the collaboratory to impact scientific outcomes:

> *Once we get [the collaboratory], I think that we'll…examine these virus particles in terms of their physical character before and after treatment…Then it will be much easier…to interpret what's going on based on what we know about the virus…Once we begin to explore…viruses as structures…we're going to hopefully be able to start directing changes to achieve changes in the physical properties that we would perceive as desirable or interesting.*

[3] A description of this phenomenon can be found in [Latour].

Three scientists also saw the collaboratory as impacting computer science research outcomes in the areas of network protocols and tele-presence.

Thus, natural scientists perceive that a scientific collaboratory may have a positive impact on scientific outcomes but this is not at all certain. These perceptions may be attributable to scientists' skepticism regarding any new instrument, and it is an important expectation to consider. When a new instrument does not provide a definite positive result in a timeframe judged reasonable by a scientist, he or she may determine that their negative expectations are confirmed and decide not to adopt the instrument, irrespective of any subsequent improvements to the instrument.

3.4 Expectations with respect to Experiment Tasks

Six study participants discussed advantages and/or disadvantages the collaboratory may provide with respect to tasks that occur during scientific experiments. Some scientists, primarily students and postdoctoral fellows, raised concerns regarding the division of tasks and control. With the stand-alone, single user nM, they typically prepare scientific samples and conduct experiments using the samples independently. A faculty advisor or peers may occasionally observe the portions of the experiment, but would not change any instrument settings or otherwise take control of the instrument or experiment. Not being present during the experiments gives students an independence and freedom to recover from mistakes and explore their own ideas. Students wondered if this would change with the collaboratory.

> *If I'm the [nM] operator [conducting an experiment], I don't know if I want everyone changing my settings.*
>
> *If [another scientist] can ask questions, very detailed questions, then I guess…[it's okay] as long as no one gets their feelings hurt.*
>
> *I think a lot of us [students] kind of find something and then we don't tell [the senior scientist] because it's not exactly perfect and we want to show him the best work that we have, and so we hold back until we have the best…he gets all excited and angry that we haven't told him, but…*
>
> *I think if I am able to do the experiments myself, than I'd prefer to do them myself because I think…it may go faster that way because I know already everything to do.*

In comparison, more senior scientists thought that being able to conveniently participate in an experiment, performing tasks, would be beneficial.

> *Interviewer: Do you see yourself in an observational role of watching what [a student] does, or…actually doing some [tasks during an experiment]?*
>
> *Senior scientist: Clearly in the beginning an observational [role] because I don't think I feel confident enough that I can do things that wouldn't damage [the instrument]…It's a matter of exposure. I feel after that I would be very inclined to participate [and perform tasks] because…there are things [I] would like to be able to know on [my] own.*

Thus, all study participants anticipated that the collaboratory would allow more participation during experiments. However, some scientists who typically conduct and control actual scientific tasks perceived this compatibility as a relative disadvantage over current practice, and others perceived it as a relative advantage. Orlikowski [11] and Schur, Keating, Payne, Valdez, Yates and Myers [13] found similar concerns among employees and scientists when groupware and collaboratory systems were introduced into their work environment.

3.5 Expectations with respect to Personal Convenience

Not surprisingly, as the definition of collaboratories suggests, six scientists reported they expected the collaboratory to provide advantages that made collaborating across distances more convenient. Reduction of travel time was mentioned as well as difficulties in finding a parking space and the number of parking tickets received. As one scientist explained when discussing the last meeting he had with his collaborator at a university campus:

> *[The last face-to-face] meeting went a little long. I put in enough quarters [in the parking meter] to last [the duration of] the meeting and a half-hour longer. [The meeting] went 35-minutes long. That's when I got my parking ticket. So one thing that hopefully will be different is [that] I won't get parking tickets.*

This story is somewhat humorous and told partially in jest, however, four scientists specifically mention problems with parking. Travel time between the scientists' locations was 20 to 45 minutes. Proponents of collaboratories often mention their advantages with respect to elimination or reduction of travel time, costs and safety risks. However, even when travel distances are short, there are still inconveniences, such as finding appropriate parking, that scientists hope a collaboratory will eliminate or reduce.

Another aspect of personal convenience focuses on management of one's own personal workloads and spontaneity of interaction.

> *The ability to have [the collaboratory system] here so we can actually look at the manipulator and do experiments from our setting…is excellent because I'll always end up where there's never enough time to get done the things we need to do…something has to give…The way I envision this working [is] that with the [collaboratory] screen here, we could see what was going on [during an experiment] and we could participate which [means]…it would be minimal effort to divert from doing something in my office or in the lab to stopping and going over to the screen and basically seeing what they were doing or asking a question … that part of it is extremely attractive.*

These findings echo previous research (e.g., [8]) regarding inconveniences that geographic distances between collaborators introduces, and provide an additional explanation regarding these inconveniences. That is, going to a difference environment causes a diversion from a scientist's current and, perhaps, more pressing tasks or tasks more immediately at hand. The opportunity to participate in an experiment from one's own office or lab as afforded by a collaboratory is a relative advantage.

4. DISCUSSION

Previous research has shown that innovations are more frequently adopted when individuals perceive that the innovation meets, or exceeds, their expectations. Thus, it is important to understand scientists' expectations regarding scientific collaboratories. Without such understanding, collaboratories run the risk of not being adopted. This is an important issue for scientific collaboratories due to their development costs and statistics regarding their modest use.

Scientists' expectations reported in this study have some aspects in common with previous research. The study participants reported they anticipated the collaboratory could provide advantages with respect to eliminating or reducing inconveniences imposed by traveling between research labs and offices, and supporting K-12 scientific education and access to specialized scientific resources by students and scientists at smaller universities and colleges.

However, results further indicate that scientists have additional expectations; in particular, expectations with respect to strategic plans, management of the scientific process, scientific outcomes, scientific tasks and personnel convenience. Most surprising are those expectations focused on strategic plans and management of the scientific process, especially when compared to the lack of positive expectations regarding scientific outcomes and negative expectations regarding scientific tasks. The scientists perceived the collaboratory as a means to achieve other long-term goals and addressing team building issues that were not necessarily related to the scientific experiments or questions they were planning to investigate using the collaboratory. In comparison, definitions and descriptions of scientific collaboratories found in the literature and on the Internet typically focus on the latter.

Interestingly, no study participant expected the collaboratory to provide the same advantages that physical co-location provides, such as opportunistic interaction. This suggests that scientists may perceive that the other advantages they mentioned have a higher priority. Of course, an alternative interpretation is that scientists may not be aware of benefits afforded by opportunistic interaction. Further investigation would be needed to examine this issue.

These results raise new questions for the evaluation and design of collaboratories. It suggests we should not solely evaluate collaboratories based on usage statistics (e.g., total number of users and time users are connected), or based on its immediate role in the production of traditional scientific outcomes such as publications and patents. Rather, it implies that we should look for longer-term and intangible measures such as new and continued (or sustainable) relationships among scientists, and subsequent, longer-term creation of new knowledge. It challenges us to understand how we can best design collaboratories to support the creation and maintenance of long-term relationships and activities that support a variety of personal and organizational strategic goals – in addition to striving to support the synchronous and asynchronous execution of scientific data collection, analysis and dissemination. How can collaboratories facilitate scientific career growth, organizational growth, and the process of science?

The study reported here is part of a larger, long-term study focusing on the design and evaluation of a scientific collaboratory. Other activities included observing scientists collaborating using the single-user nM and developing scenarios of use and detailed design requirements in collaboration with scientists [14]. The nM collaboratory has been deployed and subsequent research will discuss the relationships between the expectations reported in this paper and the adoption and/or non-adoption of the nM collaboratory.

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