AC 2011-2075: ADAPTION OF A VIRTUAL LABORATORY CURRICU-LUM: A PRELIMINARY STUDY OF IMPLEMENTATION AT OTHER IN-STITUTIONS

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Adaption of a Virtual Laboratory Curriculum: A Preliminary Study of Implementation at Other Institutions

Abstract

This paper describes the adaption and implementation of the Virtual Laboratory Project from its home university to other institutions. In the Virtual Laboratory Project students do not interact with real equipment to obtain data, but rather with computer simulations of laboratory equipment, obscured by noise. This innovation was developed with the intent of complimenting physical laboratory experiences by allowing future engineers to practice designing experiments, analyzing and interpreting data and making informed choices based on their analysis, skills they will need in industry. The idea of using virtual laboratories to facilitate project based learning is compelling since, once the software has been developed, the cost to transport a virtual laboratory to a new institution is relatively small, consisting mostly of developing teacher expertise.

Understanding and planning for the transportability of educational interventions is being emphasized by funding agencies at the national level. The aspects of transportability specifically studied in this paper include usage history and current adoption information, the Virtual Laboratory Project's perceived sources of effectiveness, barriers to implementation and adaptations made during the implementation process. This paper is a subset of a larger investigation on student learning in virtual laboratories. Artifacts of implementation and teacher and student perceptions were the primary data sources for this investigation.

Thus far, the Virtual Laboratory Project has been adapted to high school, community college and other university settings and implemented in a total 15 institutions and 59 cumulative classes. Some of its perceived sources of effectiveness include the industrially situated context which is reinforced by the budget, and the components that afford students the ability to quickly and easily collect authentic data. This preliminary report suggests that this learning environment may have the potential for widespread adoption and adaptation; however, additional research is needed.

Introduction

Transportability is a widespread goal of education research and curriculum development. If an intervention is effective in one environment, many developers want to share the intervention with other teachers and institutions to have a larger impact and improve the educational process as a whole. Often developers of curricular interventions provide suggestions for implementation, curricular materials, and support; however, one aspect commonly missing is more reflective and evidence-based description of the implementation process as technical and pedagogical innovations move from the institution at which they were developed to other institutions with different faculty, different students and a different culture.

The need for more systematic understanding has recently been emphasized at the national level. The President's Committee of Advisors on Science and Technology Panel on Education Technology reported in 1997 that significant investment needed to be made in understanding learning and supporting the development of best practices. In supporting best practices, the

report emphasized the need for large-scale studies to determine best practices and provide information on generalizability.[1] The Interagency Education Research Initiative, formed in response to that report, was created to support research and develop a knowledge base to "support the development, testing, and implementation of scalable and sustainable interventions to improve teaching and learning, particularly through the use of technology."[2] Additionally, funding agencies like the National Science Foundation (NSF) require a "broader impact" component in all grant proposals.[3] Transportability is specifically emphasized in the new Transforming Undergraduate Education, in Science, Technology, Engineering and Mathematics (TUES) Program, which requires transportability as a main component for funding of proposals.[4] The Institute of Education Sciences (IES) specifically listed "Scale-up Evaluation" as a research project goal in the most recent Request for Applications and approximately two percent of IES funded projects since 2004 had the goal of researching scale-up evaluations.[5]

This paper describes the adaptation of a virtual laboratory curriculum from its home university to other institutions. The Virtual Laboratory Project developed at Oregon State University is very early in the scaling or diffusion process. This innovation's eventual fate is unknown, but investigation of the process at multiple stages is useful for informing future work, both within this project as well as for others. This paper presents preliminary results intended to assess the current adoption, investigate sources of the innovation's effectiveness and examine issues and adaptations of this industrially situated Virtual Laboratory Project during implementation in various settings.

Transportability and Scale-up
Transportability is a broad topic that is difficult to research and assess. The ultimate question in this type of research is what works, with whom, where and in what conditions? It is concerned with both the overall diffusion of an innovation as well as the details of that process in assessing changes and effectiveness.

Diffusion of innovations is a theory put forth by E.M. Rogers in his first book on the topic in 1962.[6] Diffusion of innovations has been used as a theoretical framework for decades and has accounted for more than 5,000 publications in the field. According to Rogers "diffusion is the process in which an innovation is communicated through certain channels over time among the members of a social system."[6] Characteristics that contribute to the rate at which an innovation is adopted include relative advantage, compatibility, complexity, triability, and observability. The innovation-decision process used by an individual in consideration of adopting an innovation consists of five stages "(1) from first knowledge of an innovation, (2) to forming an attitude toward the innovation, (3) to a decision to adopt or reject, (4) to implementation of the new idea, and to (5) confirmation of this decision."[7]

Assessment of implementation is emphasized in the literature because of the major role it plays in evaluating the effectiveness of interventions. Implementation of an educational intervention may be performed with fidelity or adaption. *Implementation fidelity*, also known as integrity or adherence, is defined as "the degree to which teachers and other program providers implement programs as intended by the program developers."[8] Implementation fidelity has been used to assess interventions and training in parenting, suicide prevention, drug abuse prevention, violence prevention and many other programs. However, recreating the original implementation

as intended by the developers is challenging in practice. *Implementation adaption*, also known as adaptation, reinvention, or flexibility, allows for modifications to an intervention in order to suit the needs of the individual teachers and program providers. The acceptability of adaptation has been in debate since the 1980s,[8] and has recently turned to a closer examination of what kinds of adaptations are acceptable.[9]

Coburn pointed out that there was tension between the viewpoints of *scaling-up* via implementation fidelity versus scaling-up via implementation adaptation and further argued that scaling-up was more than just the use of an intervention in multiple settings, but included other factors.[10] Coburn proposed a conceptualization of scale that includes dimensions of depth, sustainability, spread, and shift. Dede added to Coburn's conceptualization of scale with a dimension of evolution.[11] From a design perspective, innovation development within those five, interrelated dimensions might necessitate certain activities[12]:

- *Depth*: conducting evaluation and research to understand and enhance causes of effectiveness;
- *Sustainability*: adapting to inhospitable contexts via developing hybrids tailored to adverse conditions;
- *Spread*: modifying to retain effectiveness while reducing the level of resources and expertise required;
- *Shift*: moving beyond "brand" to support user ownership as co-evaluators, co-designers, and co-scalers; and
- *Evolution*: learning from users' adaptations to rethink the innovation's design model.

McDonald emphasizes the importance of the context in which an intervention is implemented, a point of view that supports careful and evidence based adaptation of an intervention to suit different contexts.[13] Dede also emphasized the adaptation of innovations and summarized scale-up as "adapting an innovation that is successful in one setting to be effectively used in a wide range of contexts."[11]

This paper integrates perspectives from both the diffusion of innovation theory and the scale-up framework. We use the diffusion of innovation theory particularly to track the metrics of the adoption process while scale-up provides a beneficial framework to characterize the important and unique attributes of the innovation.

Research Design
The research design is presented loosely in the form of the diffusion of innovations framework while incorporating Dede's scale-up and innovation development framework. The timeline is presented first, to provide context. Next, the innovation is described along with evolution of the innovation at the home institution. This description includes the authors' expected sources of effectiveness. Communication channels are expressed in two parts, the selection of initial institutions for adaptation and implementation, and the widespread dissemination of the Virtual Laboratory Project via additional diffusion mechanisms. The social system, while complex is partially described with participants in the Methods section, and further explored in the Results and Discussion section.

Timeline

The development, implementation and scaling of the Virtual Laboratory Project has thus far consisted of four phases:

1. Initial development, implementation and revision of the innovation at the home institution.
2. Careful adaptation and implementation of the innovation at three additional institutions.
3. Workshop development based on student learning assessment and scaling information from Phases 1 and 2.
4. Workshop delivery and open use with developer approval.

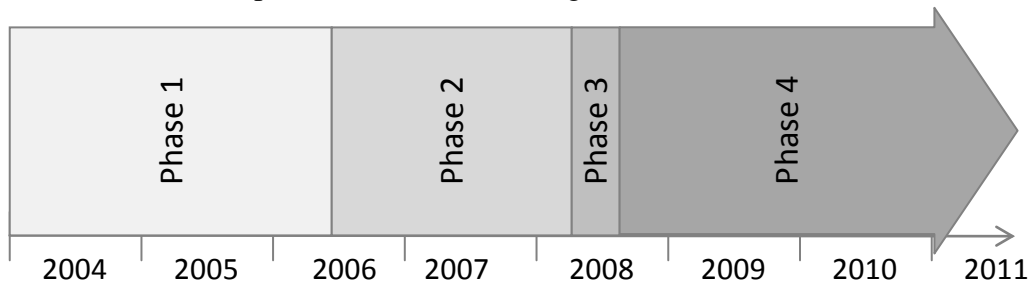The timeline for these four phases is described in Figure 1.

Figure 1. Timeline of the development, implementation and scaling of the Virtual Laboratory Project

The Innovation – Industrially Situated Virtual Laboratory Project

Over the past seven years two industrially situated virtual laboratories have been developed, implemented, assessed and disseminated. While they differ in topic, they are similar in other aspects and are both referred to as the Virtual Laboratory Project because of their similarities. Both virtual laboratories are based on engineering principles and use detailed mathematical models. Both also give the teacher the option to incorporate process and measurement error. In the Virtual Laboratory Project, learning occurs not by direct interaction with the software, but rather through interaction with team members, teachers and other resources that is mediated by the software. The Virtual Laboratory Project is not intended as a replacement for physical laboratories. We believe hands-on physical laboratories are essential to learning engineering. The Virtual Laboratory Project, however, was intended to compliment the experience of physical laboratories by minimizing the difficulty in performing experiments and allowing students to focus efforts on strategically designing their experiments, analyzing and interpreting data and making informed choices based on their analysis. In this way, this innovation scaffolds problem solving that students would not have the time or resources to accomplish otherwise.[14]

The Virtual Laboratory Project was initiated based on four learning objectives[15]:

1. Promote development of creative and critical thinking in a way that applies core concepts from the curriculum.
2. Engage students in an iterative experimental design approach that is reflective of the approach used by practicing engineers.
3. Provide an authentic context, reflective of the real-life working environment of a practicing engineer, such as working with a team to complete complicated tasks.
4. Promote a learner-centered approach to an open-ended design problem which results in an increase in the student's tolerance for ambiguity.

The delivery of the project at the home institution lasts for three weeks. In the beginning of the first week of the Virtual Laboratory Project, the laboratory instructor introduces the faculty member who serves as the subject matter expert. The expert presents background technical information, introduces the virtual laboratory software and presents the objectives of the project during two, 50 minute class periods. A timeline, list of deliverables, and description are shown in Table 1. The expert also meets with student teams at schedule times during the project to provide feedback.

Table 1. The timeline and description of the Virtual Laboratory Project.

Timeline	Deliverables	Description
Project Introduction		Expert presents introductory manufacturing context, engineering science background, the Virtual Laboratory Project software, and project objectives and deliverables.

End of Week 1	• Design Memo Meeting (DMM)
	   o Initial run parameters
	   o Experimental strategy
		Student teams meet with the expert to discuss design strategy. Upon approval of strategy and parameters, students are given a username and password to access the Virtual Laboratory Project.

End of Week 2	• Update Memo Meeting o Progress to date	Student teams meet with expert to discuss progress, issues, and receive feedback.
End of Week 3	• Final Recipe • Final Report • Final Oral Presentation • Laboratory Notebook	Teams deliver a 10-15 minute oral presentation to the expert, 2 other faculty members, and the other students in the laboratory section. The presentation is followed by a 10-15 minute question and answer session.

The Virtual Laboratory Project as delivered at the home institution is very open-ended, unlike laboratory experiences earlier in the curriculum. Many physical laboratories are described as confirmation experiments, with clearly defined operating procedures where strategic focus is on finishing on time or troubleshooting malfunctioning equipment within tight time constraints. In the Virtual Laboratory Project, students must optimize reactor performance with very little procedural or strategic information provided. The increase in cognitive demand in the strategic domain is balanced by the decrease in demand in the haptic domain. Instead of spending time and cognitive resources assembling equipment, and initiating and maintaining functionality of instrumentation, students are able to use their resources to manage a budget, create and carefully plan the project strategy, and analyze and assimilate the information from multiple experiments that were easily run. The process of running the reactor once, taking measurements, and exporting the measurement data to excel takes approximately 3 minutes.

Virtual Chemical Vapor Deposition Laboratory
The first industrially situated virtual laboratory discussed in this work, the Virtual Chemical Vapor Deposition (VCVD) laboratory, was designed and developed in 2004 and first implemented at the home institution in one course in 2005. The original Virtual Laboratory Project consisted of three elements: the student interface (originally HTML) which facilitated data acquisition, the instructor interface that allowed for control and assessment of student results, and the instructional design which wrapped the project in an industrial context and set forth student objectives and deliverables. In 2005, after the initial implementation a 3-D interface

was constructed, that closely resembles a microelectronics industry cleanroom, as a potential replacement for the HTML interface. The HTML interface was maintained however, for institutions that could not accommodate the 3-D interface.

The VCVD laboratory project tasks students with the development of a process "recipe" for a low pressure chemical vapor deposition reactor in high volume manufacturing. Optimization includes both the uniformity of the deposited silicon nitride (Si_3N_4) film, as well as utilization of the reactant gas while minimizing development cost. Students are charged per run and per measurement point. This project is situated in the context of the integrated circuits industry. Students are required to keep a detailed laboratory notebook, similar to those kept in industry, which should contain observations, strategies, analysis, results and logic. In order to optimize the process, the students control nine process parameters: reaction time, reactor pressure, flow rate of ammonia, flow rate of dichlorosilane (DCS), and the temperature in five zones in the reactor. After entering and submitting parameters to run, students may implement their measurement strategy in which they choose the number and position of wafers to measure, as well as the number and position of points within each wafer. The results of measurements can be viewed in the program or exported to an excel file where further analysis can take place.

Virtual BioReactor Laboratory
In 2007 a second virtual laboratory was added, the Virtual BioReactor (VBioR) laboratory. This second virtual laboratory was added to appeal to bioengineering and environmental engineering students. While the scientific content was based on a different subject, the VBioR laboratory shared the same learning objectives, a similar theory-based model with error, a similar type of instructor interface and an HTML student interface. In 2010, a web-based 3-D interface was developed for the VBioR. In the VBioR laboratory students are tasked with optimizing volumetric productivity by controlling temperature, substrate concentrations, cultivation times (both batch and fed batch), and feed flow rate. Students also choose when and what to measure. Every run and every measurement costs virtual money. The project is situated in the context of either production of a recombinant protein (as might be found in the pharmaceutical industry) or waste degradation (typical of waste water treatment plants). Additional details of implementation and student learning in the VCVD laboratory and the VBioR laboratory have been previously published.[16,17]

Characteristics and Sources of Effectiveness
Characteristics of the Virtual Laboratory Project that, according to the diffusion of innovations theory, influence the diffusion process include compatibility, complexity, triability, observability, and relative advantages. In the Virtual Laboratory Project, learning outcomes are compatible with those of many teachers; however, as discussed in the Results and Discussion section, IT infrastructure may pose a different kind of compatibility issue. The Virtual Laboratory Project may be perceived as complex due to the topic and the technology requirements. The Virtual Laboratory Project is free to use, and teachers need only contact the developers for access. It is also observable primarily via publications. As budgets are tightened and class sizes increase and the option of a free, effective educational intervention becomes more of a relative advantage.

For a more detailed assessment of the characteristics of the Virtual Laboratory Project, it is useful to frame it in terms of "sources of effectiveness," an important component of the scale-up framework. Identified sources of effectiveness as assessed by student learning investigations and developer perception are presented in Table 2 along with the affordances these sources of effectiveness provide.

Diffusion Mechanisms
As with most new innovations, the Virtual Laboratory Project environment described in this paper first required development, implementation, assessment and revision at the originating institution. During this time, assessment included examination and improvement of the project environment and scientific study of student learning, results of which were disseminated via primarily conference publications.

Phase 2 of the Virtual Laboratory Project scaling proceeded over the next three years (2006, 2007, and 2008). A series of careful implementations of the innovation were performed at two universities and one high school (one per year with the high school being the last). In all cases, a graduate student from the home institution was paired with the teacher in order to facilitate implementation. All teachers in this stage of implementation had chemical engineering experience and in the first two cases the teachers had project specific expertise. In two cases, the graduate student assisted in actual presentation of the implementation. For the high school, the instructional design was modified in order to suit the needs of the teacher and the lower educational level of the students. Scaffolding was developed and took the form of a homework worksheet prior to presentation of the project, two walk-through worksheets intended to introduce students to the environment and assist in the first exploration of variables and an optimization assignment. A more detailed description of the first implementation of the Virtual Laboratory Project at the high school level in an Introduction to Engineering class and Chemistry classes is available elsewhere.[18]

In Phase 3, the information gained from the careful implementation efforts was combined into materials for a workshop on the Virtual Laboratory Project. Materials included project assignments, presentations, curricular schedules, and student learning information. A workshop binder was created as a resource for workshop participants to reference; it included all workshop presentations and curricular materials as well as background information on the Virtual Laboratory Project topic and software installation instructions. These materials were also made available to instructors via the password protected instructor interface website.

Phase 4 consisted of holding workshops based on the workshop materials and open dissemination of the Virtual Laboratory Project. Workshop participants were solicited via word of mouth, personal promotion by the developers and collaborators, flyers posted on the home institution website, and an advertisement in a teacher association publication. In order to use the Virtual Laboratory Project in classes, a teacher need only contact the developers for a teacher account. There is no charge for use of the Virtual Laboratory Project; however, users were requested to provide documentation in order to satisfy grant requirements. Technical support is offered to users as requested, with no charge. A detailed description along with assessment of two of the workshops is described elsewhere.[18] A summary of diffusion activities is shown in Figure 2.

Table 2. Sources of effectiveness and affordances of the Virtual Laboratory Project.

|	Sources of Effectiveness	Affordances
Instructional Design	Project Objectives	Multiple design objectives emphasize design strategy and integration of appropriate domain knowledge. These also link to the situated nature of the project, along with the budget and industrial context. The students value the project because the objectives are real - high quality product at low price (both development and production).
	Budget	Cost constraint makes students value runs which emphasizes planning and discourages "video game" mode. The budget reinforces the authentic nature of the project.
	Coaching	Feedback from teacher facilitates integration of prior knowledge and reinforces the industrially situated nature of the project.
	Worksheets	Used at the high school and community colleges, worksheets provide level-appropriate scaffolding to allow access at all levels.
	Formal Communication	Induces student reflection and organization of thoughts, including team negotiation. Provides opportunity for instructor feedback
	Teams or Individuals	Structuring student groups promotes peer instruction, team negotiation, collaboration and project management.
	Industrial context	This affords student to value the project. They take ownership of the project because they feel it is helping to prepare them for careers and ties to the real world. They feel the skills that they are using to solve the problem are tools that they will use in the workplace. The budget plays a role in supporting the industrial context.
Student Interface	3-D	Represents the authentic environment of an authentic IC factory. Reinforces the sequence of procedures to obtain experimental data. Students also enjoy this aspect as a "fun" part of the project.
	HTML	Allows Institutions that are technology challenged to use the project.
	Reactors and measurement tools	Allow students quick and easy data acquisition which allows for iterative design.
	Data display and export	Allows students to integrate engineering science knowledge and apply statistical methods to analyze results from an experiment.
	Cost tracking	Reinforces budget and industrial context, allows for easy budget tracking.
	Theoretical Model	The rigorous model reinforces the authentic nature of the problem. Students believe the results could be obtained in a real IC factory. Including measurement and process error is critical to the authentic nature of the problem. An over simplified model would make the experience much less real.
Teacher Interface	Student account setup	Allows teachers to assess individuals or groups of students in terms of budget, progress and performance and use that information to provide feedback. This also allows the teacher to restrict usage until students have formulated a plan.
	Student progress	Allows teachers to incorporate dynamic assessment of student progress and performance into feedback.
	Reactor customization	Allows task characteristics to be changed from year to year which can be used to combat "institutional knowledge."
	Instructional materials	Provides resources for new teachers to learn about the technology and materials for implementation.
	Class history	Allows comparison of performance from previous years.
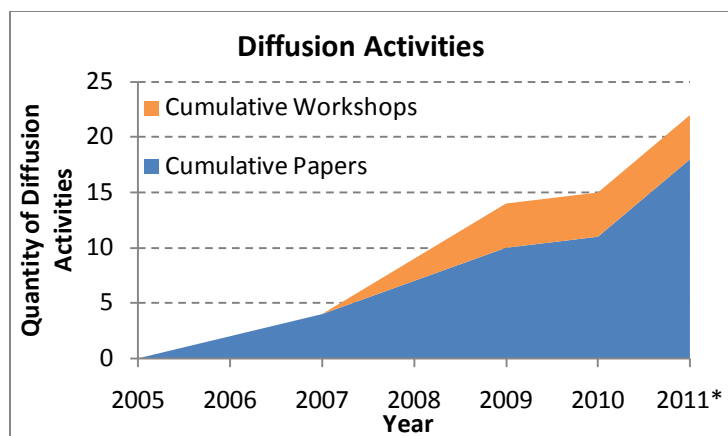
Figure 2. Summary of diffusion activities, growing from zero in 2005 to the current total of 18 published or accepted papers and 4 workshops. *values for 2011 include the current number of accepted papers and zero additional workshops.

Methods
Participants
Participants consist of individuals from 12 institutions total, five of which were universities (offering undergraduate and graduate degrees), two were community colleges, and five were high schools. This research was approved by the institutional review board and all participants signed informed consent forms.

Students from the home institution and three other institutions were interviewed and/or surveyed. Students surveyed at the home institution consisted of all students that participated in the project. Interviews were conducted with students in two cohorts at the home institution; selection of these students was based on their participation in a larger research study on student learning in virtual laboratories. The process for choosing these students addressed several factors including schedule, gender distribution, and perceived willingness to comply with research study requirements. Students' academic performance (e.g. GPA, class standing, test scores) was not a contributing factor in selection at the home institution. Students surveyed and interviewed at the remaining three institutions were selected by the teachers at those institutions and represent three cohorts and four classes in which the Virtual Laboratory Project was implemented.

Teachers were either surveyed or interviewed. The teachers surveyed consisted of individuals that had been participants at workshops on the Virtual Laboratory Project. One post-implementation survey was completed after the teacher had implemented the Virtual Laboratory Project in their class. A small stipend was offered to some workshop participants (multiple workshops were presented with a stipend only offered at a fraction of them) for attending workshops, with a subsequent stipend offered if participants implemented the Virtual Laboratory Project and submitted the post-implementation survey with required documentation. Interviewed teachers included workshop participants and non-workshop participants, all of which had implemented the Virtual Laboratory Project in their curriculum.

Data Collection & Analysis
Data sources included three broad categories: (i) history of Virtual Laboratory Project usage (e.g., number of users, number of classes, number of institutions over time), (ii) artifacts of

implementation (e.g., lesson plans, project assignments and summaries of student information), and (iii) participant perceptions (e.g., student and faculty questionnaire responses and audio recordings, transcripts, and notes of semi-structured interviews).

The Virtual Laboratory Project history of usage was analyzed for adoption rate and cumulative adoption and usage. Project implementation timelines and artifacts were compared directly and used to assess adaptations made in the different settings. Surveys and interviews were examined for common themes, a subset of which was tied to either sources of effectiveness of the innovation or barriers to adoption. Teacher perceptions and student perceptions were used as indicators of the sources of effectiveness.

Results and Discussion
Current Adoption
To date a cumulative total of 15 institutions have implemented the Virtual Laboratory Project in a cumulative total of 59 classes (a class in which the Virtual Laboratory Project was used multiple years is counted for each year). Adoption of the Virtual Laboratory Project over time is shown in Figure 3.
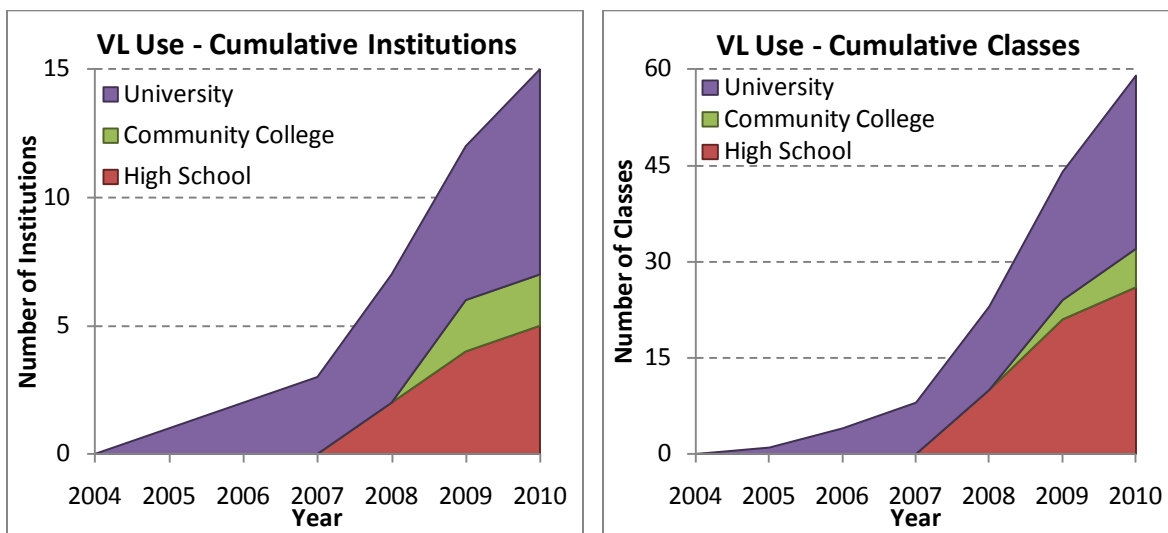

Figure 3. Virtual Laboratory Project cumulative use over time with number of institutions (left) and number of classes (right)

In 2008 and 2009 high school adoption of the Virtual Laboratory Project contributed greatly to the overall adoption. This corresponds to the workshops that were delivered, two in 2008 and two in 2009. The majority of high school teachers that have implemented the Virtual Laboratory Project in one of their classes attended one of the workshops prior to implementation, the only exception being the initial high school implementation. In addition, both community college teachers that have used this innovation attended one of the workshops. By contrast, more than half of the universities, other than the home institution, were introduced to the innovation through one-on-one interaction with one of the developers.

Considering the usage information of the Virtual Laboratory Project, some institutions have continued use every year since initial implementation, others use it in a course offered every

other year, and still others have scaled down use or ceased to use the Virtual Laboratory Project. Nine of the 15 institutions that have used the Virtual Laboratory Project have used the innovation for more than one year, and three institutions used it for the first time in 2010. Of the six teachers that completed post-implementation surveys, 100% stated that they intended to use the Virtual Laboratory Project again. The majority of those interviewed also expressed interest in using the Virtual Laboratory Project in subsequent years.

Sources of Effectiveness

In this preliminary report of findings, some of the authors' expected sources of effectiveness were found to be reinforced by both teachers and students interviewed and surveyed. One of these sources was the situated, industrial context of the instructional design. Three questions on the post-implementation survey elicited responses consistent with this source of effectiveness:

- What need in your teaching did the laboratory address?
- What specific content, concepts, and/or set of cognitive skills were you able to address with this virtual laboratory?
- What is the value added in the use of the virtual laboratory?

Five of six teacher participants that completed post-implementation surveys expressed that the Virtual Laboratory Project provided a realistic experience for students in either an engineering or scientist position. Participants further commented on the benefits of the workplace scenario. In addition, the same questions were asked of students at one of the universities and more than 41% of the 60 students either explicitly referred to the "real world" scenario or heavily eluded to the "real world" context. The following student responses reinforce this point:

> *"It allowed us to do some of the real problem solving that we might have to do in our careers."*

> *"It allowed us to apply knowledge to real life situations."*

Interviews of teachers were also consistent with the surveys on this point:

> *"this [the virtual laboratory project] is one way that we are definitely doing it, allowing them to act like real scientists and real engineers"*

> *"the CVD is one of the only examples we have to give them where they get a glimpse of what it might be like to take this little thing and scale it"* [referring to scaling it to an industrial size and manufacturing setting]

Interviews with students were also consistent, with many students emphasizing the "real world" aspect of the project.

At the university level, the budget, another perceived source of effectiveness, was noted to reinforce the situated nature of the project by both teachers and students. Furthermore, one institution placed little emphasis on the budget and the project appeared to be less successful. However, drawing conclusions is difficult as there are several factors that affect the success or effectiveness of the project. Further investigation of what conditions make the budget a significant source of effectiveness is needed.

Other sources of effectiveness that were reinforced by teachers and students were the theoretical model and the reactors and measurement tools, which combined to allow students to easily and reliably collect authentic data. This feature affords students the ability to perform iterative experimental design and analysis. An interview with one of the teachers illustrates this well:

> *"the pros of the virtual lab are that they do get it to work and they get lots of data and so there's a much greater opportunity to look back to theory. Um, so it's as if they've spent six months in the lab, you know, at the end of six months they might actually have their [experiments] working well enough that they can connect back to theory and so that certainly is really helpful."*

The majority of students interviewed expressed that they appreciated that they could gather data easily without worrying about equipment troubles.

> *"I found it to be one of our more helpful projects because I felt that we got to go more in depth with it than some of our other labs because some of our other labs have so many things that go wrong because we have like cheap [equipment] and stuff like that. So it was nice that we didn't really have to deal with that at all."*

> *"for the virtual lab, the lab equipment worked. Ha ha huh, 'cause like with many of the other labs they're like 'ok this kinda works.' And you know, it's like ok take this reading and this part of the equipment doesn't quite work and so it's just kind of like work arounds. And like oh look the hoses you know and now it broke off and it's squirting water all over. You know, so it was nice to have…a lab that we could access any time and it would function"*

Preliminary data support the budget, reactors and measurement tools, theoretical model and industrial context as sources of effectiveness. The remaining sources of effectiveness require investigation into how they align with teacher and student perceptions and in what ways the current list warrants revision.

Barriers to Adoption

Two potential disadvantages regarding the Virtual Laboratory Project are information technology and preparation time. Two of the six teachers that completed post-implementation surveys commented on issues with the IT infrastructure and could not install the 3-D interface. One of these teachers also noted that they had spent preparation time attempting to install the 3-D interface, but ended up using only the HTML interface. In fact, two teachers noted that they spent time attempting to obtain permissions to install the 3-D interface, something that was also emphasized as an issue in two interviews. Other technology based interventions also have faced challenges.[19]

Of the seven teachers that specified preparation time needed for this project, the shortest amount of time was two hours and the longest was 30 hours. The average was approximately 12.5 hours (rounding to the nearest half hour). In general, teachers with more domain expertise would be expected to require less preparation time; that seems consistent with findings thus far, but additional factors most likely contribute to required preparation time. One teacher that was interviewed had attempted to get colleagues at the institution to implement the Virtual Laboratory Project as well. This individual stated that the biggest barrier for colleagues was:

"for them to take the time to meet with me to learn it, to understand it, and then to work it into their curriculum."

While preparation time may be a barrier for some teachers, one of the teachers compared the preparation time for the Virtual Laboratory Project to physical laboratories they had implemented and expressed a contrary point:

"So the effort for me was, I mean, basically nothing compared to the other labs. You know, I mean I did spend probably 15-20 hours going through stuff but, um I didn't have to...deal with all of the frustrations, with ordering different things, equipment. And, um, when I started some of the other labs I had to do a literature search and you know, really try things in lab by myself. So I'd say it was a lot easier than some of those other labs."

Disadvantages or barriers for teachers to implement the Virtual Laboratory Project need further investigation to assess them more thoroughly. However, based on this preliminary data, software improvements may be considered (e.g. a web-based 3-D interface) in order to integrate more easily with existing IT infrastructure. Additional teacher scaffolding in the form of a "getting started" packet or short video tutorials may also be options to consider.

Adaptations

Several adaptations were made to the Virtual Laboratory Project as it was implemented in various settings. Two adaptations that illustrate the differences in The Virtual Laboratory Project across educational levels include the level of scaffolding provided to students and the time allotted to the project. As expected, the amount of scaffolding required for the various student educational levels decreased with increasing educational level. A greater amount of scaffolding was deemed necessary for high school students than for community college students and even less scaffolding was presented for university students. High school students were provided with more background information, additional homework, and walk-through worksheets in order to help them familiarize themselves with the virtual laboratory background, software and context. In some cases the high school curriculum consisted of as many as five background homework assignments, walk-through worksheets, or problem statement assignments which were intended to scaffold the student approach. This contrasts to university cases, in which students were given as little as one problem statement regarding the project. In all cases, however, student-teacher interaction, either in class, office hours, small group discussions, or scheduled meetings was incorporated into the project.

In addition, supervised, in-class time devoted to the project varied widely between the different levels, with high schools and community colleges devoting the most supervised, in-class time. However, students at the university level were often given unsupervised lab time to complete the project. Total time spent on the project by students was reported to be highest, at the community college and university levels, with an average total of approximately 24 hours and students reporting as many as 50 hours spent on the project. High school students were estimated to have spent only an average of approximately 12.5 hours total on the project.

Some of the other adaptations include method of project presentation, specific project assignment, and presented project context (e.g., one teacher presented the Virtual CVD Laboratory Project in the context of biochip manufacturing as opposed to the typical context of

traditional integrated circuit manufacturing). While many adaptations were made during project implementation, future investigation is needed to fully characterize these adaptations and their impact on effectiveness.

Conclusions and Future Work

Dissemination activities of the Virtual Laboratory Project include four workshops and 18 publications. This innovation has been implemented in a total of 59 classes, at 15 different institutions. Confirmation of two perceived sources of effectiveness of the innovation has been found in student and faculty feedback. Students perceive the innovation, as delivered in at least three of the institutions, as being situated in an industrial setting which is reinforced by both the industrial context of the software, delivery, presentation materials, and the budget. Teachers reinforce this perspective. Some data suggests that the project may be less successful or effective when there is little or no emphasis on the budget and industrial context; this aspect requires further investigation. In addition, the theoretical model and reactors and measurement tools and the affordance they provide in allowing for easy collection of authentic data were reinforced as a source of effectiveness. During implementation, IT infrastructure poses a potential disadvantage for this innovation. Many adaptations were made during the implementation process which included varying the degree of scaffolding based on the educational level of the students, and varied time allotted by teachers and students for the project. These and other adaptations require further investigation to assess their impact on effectiveness of the Virtual Laboratory Project in different contexts. This work is preliminary and while it suggests that this learning environment may have the potential for widespread adoption and adaptation, it generates more questions than it answers. Some of the research questions that are of interest for further investigation include the following:

- What evidence is present to support the other perceived sources of effectiveness and how do these change with teacher objectives and different implementation conditions?
- How do teacher objectives map onto perceived sources of effectiveness?
- To what degree do teachers utilize the existing instructional materials and what modifications are most common? How do the instructional materials tie to objectives and impact effectiveness?
- Based on analysis of student work, how do the adaptations impact the effectiveness of the Virtual Laboratory Project?
- How can the Virtual Laboratory Project be modified to make it more robust in adverse conditions?
- How does the effectiveness of the Virtual Laboratory Project change with the expertise and resources of the teacher?
- What other potential factors influence the scalability of the Virtual Laboratory Project (e.g. adopting site characteristics, teacher characteristics, student characteristics, technology resources, etc.)?

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