Teacher's Stages of Development in Using Visualization Tools for Inquiry-Based Science

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Abstract: Scientific visualization tools have shown tremendous promise in drawing today's increasingly visual learners into in-depth inquiries in mathematics and science. A critical question associated with these relatively advanced tools is how successful teachers are in using them with their students in the chronically undersupported technological settings of K-12 education. This paper describes teacher progress in using four visualization tools in terms of a stages of adoption model. Brief case studies are presented from follow-up interviews that describe how four teachers have begun to integrate these relatively advanced scientific visualization tools into their teaching practice. Discussions of modifications to the stages of adoption model and issues related to bringing scientific visualization tools into classroom teaching practice conclude the paper.

Scientific visualization tools offer a rich use of the more powerful computers that are becoming more and more plentiful in school districts today. These are a set of inquiry-based tools, many of which were originally designed to help scientists understand and explore different datasets or physical phenomenon. Visualization tools have shown great promise in drawing today's increasingly visual learners into in-depth study of scientific and mathematical topics (Baker and Case, 2000; Greenberg et. al, 1993; Gordin and Pea, 1995; Jonassen, 2000; Thomas, 1996; Malinowski, Klevickis & Kolvoord, 2001).

Both the promise and the relatively advanced nature of this software leads to the question of how to get more teachers involved in using visualization tools in their classrooms. Many projects offer extended training for teachers in one tool, but extended training in the first exposure to a new tool is often too much, too soon. Project Visualization in Science and Mathematics (VISM) is a recently completed NSF-funded project intended to focus more broadly on the techniques of visualization and not so much on particular tools. In addition, the project worked to build a cadre of trainers able to introduce teachers to visualization techniques in short, focused sessions and then enable them to go back to their classroom and try an initial lesson or two.

One of the critical questions surrounding the work of this project is what are the stages which teachers go through in adopting these new and relatively advanced technological tools into their own practice. This paper describes one research-based model of the stages of teacher development in using technological tools. Next the four technological tools that were taught to teachers in Project VISM are described: image processing, geospatial analysis, molecular visualization, and systems modeling. Then a matrix is presented that relates the ACOT model to each of the four tools used in Project VISM. Initial findings are presented based on our interviews of four teachers that describe their use of the tools with students. The paper concludes with a brief discussion that includes some refinements to the ACOT model for scientific visualization tools and a discussion of larger questions related to how teachers bring these tools into their teaching practice.

The ACOT model of stages of teacher development in using technological tools

Discussions of using inquiry-based technological tools to promote better learning in science and mathematics often begin with concerns about the preparedness of teachers to use these tools in the chronically undersupported technological infrastructures of K-12 education. In the midst of these concerns, it is often recognized that teachers progress through identifiable stages of development in using these tools in their classroom. One research-based model for these stages was first articulated as part of the Apple Classroom of Tomorrow (ACOT) project. The ACOT model suggests that teachers may progress through as many as four stages of development in using technological tools in their teaching practice (Sandholtz, et. al, 1997). Those stages are:

- *Entry* level-competent using the tool
- *Adopt* the tool into their teaching practice
- *Adapt* the tool into their teaching practice
- *Innovate* with the tool in their teaching practice

The ACOT model suggests that it often takes about three years to progress through these various stages, and that in fact adopting the tool often corresponds to the first year's use, adapting the tool corresponds to the second year's use, and innovating with the tool corresponds to the third year's use. It is important to note that this is not a causal model. We do not suggest that all teachers inexorably progress through these stages. Many remain at one or another stage of development, successfully using the tool with their students. In fact, with the proliferation of different software tools of increasing sophistication, it may not be possible (or even desirable) for many teachers to reach the innovation level with all the tools they use in their teaching practice.

Project VISM: Cross training in four scientific visualization tools

During the summers of 2000, 2001, and 2002, the Integrated Science and Technology program at James Madison University held summer workshops in the techniques and application of data visualization for math and science teachers with the sponsorship of the National Science Foundation. These were three-week long workshops intended to help teachers see the forest (data visualization possibilities in the classroom) as well as the trees (software and curricula). In contrast to many other projects that emphasize the teaching of one particular tool, Project VISM participants were asked to learn four different data visualization tools:

- Image processing with NIH Image/Scion Image or ImageJ software
- Geographic Information Systems (GIS) with ArcView GIS software
- Molecular visualization with RASMOL and Chemscape Chime software
- Systems modeling simulations with STELLA software

The overall intent of the project was to help more teachers and students involved in using data visualization to learn more about science and mathematics. 118 teachers took part in the project over the course of five separate VISM sessions spread over three summers. Summative evaluation of the project by the participants indicate that the project was very successful in meeting its initial goal of helping teachers learn to use these four different tools; the participants found the workshop to be a very valuable professional development experience (Charles 2001, 2002). Below is a brief description of each tool.

Image processing involves the manipulation and analysis of digital images. It has a significant heritage in biomedicine and planetary science research, and images can come from spacecraft in the far reaches of the solar system or from a digital camera in a student's hand. Geographic Information Systems (GIS) have been described in a recent popular journal as "mapping applications that take spatial data for a variety of topics and layer them one on top of the other in order to see a correlation that is otherwise difficult to notice" (Geographic Informations Systems in the Classroom, 2000). GIS systems are currently being used in everything from environmental research to urban planning to marketing and law enforcement. Molecular visualization is a technique that has long been in use by research scientists on high performance computers. But recently public domain software tools have become available for students and teacher to be able to create sophisticated molecular models that can be manipulated in readily available web browsers with the use of a simple plug-in. Systems modeling tools such as STELLA allow students to create a linked set of processes in a given situation without first getting bogged down in the mathematics. Teachers and students can create models of the spread of infectious diseases, or the trajectory of a water balloon, or the stresses in the life of a high school senior.

The VISM matrix: The ACOT model applied to the four tools

Deliberate discussions of the ACOT model were held with the instructors of the VISM summer workshop. Initially they were presented with a summary of the model and then asked to specify what the use of each of their respective tools would look like at the entry, adopt, adapt, and innovate level in the classrooms of the teachers in the project. In this way they were asked to make explicit their expectations for the participant's use of each tool at the end of the first summer of the project. During the second year of the project the same instructors were asked to review and revise their descriptions of the adopt, adapt, and innovate levels of classroom use of the tool that they taught to the participants. In these discussions the instructors were asked to be as realistic as possible in their description of each stage of use for their respective tool. It should be noted that these descriptions were nevertheless approximate and that part of the ongoing work of assessment in the project is to test out what uses the participants actually put these tools to use.

Table 1 lists the summary of those conversations. This VISM matrix (Charles & Kolvoord, 2001) was initially developed to assist in identifying each participant’s stage of development for each tool at the end of the first year of the project. The first column of the figure lists the four different tools and at the top of the next four columns there is a list of the four ACOT stages of tool development: entry, adopt, adapt, and innovate. For this project we defined the *entry* category as being competent to use the listed tool after the workshop was completed (see Table 1). Under each tool we listed what the instructors described as the competencies that each participant accomplished through the course of the workshop.

Tools	**Entry**-competent in using *the tool* at the workshop	**Adopt** *the tool* into their teaching practice (Year 1)	**Adapt** *the tool* into their teaching practice (Year 2)	**Innovate** with *the tool* in their teaching practice (Year 3)
Image processing: *NIH Image* or *Scion Image*	Skill set taught to participants: Open an image Manipulate LUTables Measure/set scale Profile plot/surface plot Stacks and animations Capture their own JPEG images Average images Copy/Paste images	Participants select one of the workshop activities and successfully use it with students (preferably on a regular or recurring basis).	Participants significantly modify one or more of the workshop activities into their own teaching practice.	Participants bring in their own images and apply a variety of image processing skills as part of a student-initiated inquiry.
Geospatial Analysis: *ArcView GIS*	Participants successfully completed the identified activities in the workshop ArcView project intro Exploring Projections GeoProcessing Wizard	Participants successfully do one or more activities from the workshop with their students	Participants significantly modify an activity from the workshop to fit the needs of their curriculum/students/ technical constraints and incorporate found data.	Participants can create their own GIS activity using an original data set/source
Molecular Visualization: *RasMol* and *Chemscape Chime*	All participants were successfully able to: embed Chemscape Chime structures within a web page write scripts to interact with and animate the Chime structures. They used these skills to create tutorial websites on molecules that they selected as part of the "mineral web."	Participants use existing .pdb file collections to manipulate molecules to create graphics, make measurements, and show molecular properties. Participants use the web page they created in the workshop to teach a concept in their curriculum. Participants use the list of .pdb resources (for their content area) with students.	Participants are able to find and download .pdb files from Internet sources and use those to write scripts in RasMol. Participants are able to write animated scripts in RasMol that tell a molecular story related to their teaching.	Participants are able to embed Chemscape Chime structures within a web page and write scripts to interact with and animate those structures to create tutorial websites on molecules they have selected.
Systems modeling: *STELLA*	Participants put an interactive front end on an existing STELLA model and adapt it for their own use in their teaching.	Participants operate a STELLA simulation with their students. Participants read & interpret STELLA system diagrams with their students.	Students can name and document an existing STELLA model , e.g.: Given a generic system diagram and a physical description of a system, students can name and document the model and input the equations that run the system	Students can build their own STELLA model from a written description of a system with the assistance of the participants.

Table 1. A matrix of the stages of tool use by the participants in the VISM project

The VISM matrix provides a snapshot of any given teacher's evolution in their use of the respective tools. For example, based on an interview and/or a classroom visit, a teacher might be found to be using NIH Image at the adapt level, using ArcView GIS at the adopt level, and not using either Chemscape CHIME or STELLA with their students at all. What follows is a summary of our initial findings based on interviews of teachers one year after they had taken the summer workshop and described in terms of the VISM matrix.

Follow-on interviews

Follow-on interviews are still being conducted to begin to determine how teachers are using the VISM tools in their teaching practice. The questions for these interviews were initially based on some of the written pre/post evaluation questions that each participant completed during the workshop. The interviews were conducted over the phone or face to face if possible. Summaries were emailed to participants for comment/correction and participants emailed some follow-up information. These were open-ended interviews conducted with a starter list of key questions which included:

- Briefly describe 1 or 2 projects you carried out last year with your students using one or more of these visualization tools.
- With which tools did you offer workshops during the year, and with which tools do you plan to offer workshops next year?
- What things helped you use the tools with your students, and what were your greatest obstacles in using these tools with your students during the year?
- Briefly describe what you think you accomplished this year based on your participation in the VISM workshop, and one thing you had hoped to accomplish but perhaps did not.

Four interviews have been conducted so far. Two of the teachers interviewed have tried the tools for one year and two of the teachers have tried them for two years. More interviews are planned across multiple years as well as some limited visits to classrooms, but already an interesting trend has emerged. The VISM matrix described above predicts that after one year of use teachers would generally be at the adopt level of use with any tool that they learned for the first time at VISM and at the adapt level after two years. They most likely would be at a higher level of use for any tools that they had used prior to the workshop. Ideally they might begin to create lessons or projects in which the students use more than one tool in addressing some of the same content, though this use of the tools would be very advanced.

In the initial interviews, there is one example of a teacher who has reached this level of use, though under exceptional circumstances. There are two teachers who are clearly adopting/adapting one particular tool into their practice, and actively seeking further training in the use of that tool. There is one participant who did not use these tools at all, but instead has made effective use of a different visualization tool that came to his school. This variety in implementation seemed worthy of fuller description even as interviews are ongoing.

Initial findings

Teacher one: an experienced scientific visualization tool innovator

One year after completing the Project VISM workshop, Jim has adapted one activity using RASMOL into his curriculum. He has also adopted an activity using STELLA into one of his units of study during the year. As an experienced ArcView GIS and NIH Image/Scion Image user, he has continued to work at the innovate level with these tools, bringing in new projects, activities and pedagogical approaches based on his own experience.

He described his use of ArcView in his environmental science class as "from the first week of school to the last week." In one project in that class he also used STELLA, the systems modeling tool. One major project they completed addressed a question that had been in the local news. During the summer a number of illegal immigrants had died not far from his school in Arizona while attempting to cross into the United States from Mexico. One of the policy proposals resulting from this terrible event was to place watering stations out in the desert to prevent future tragedies. He and his students examined the question of what the effect of these watering stations might be on safety and health of the immigrants by creating a map in ArcView. They also used a teacher-created STELLA simulation during one period that modeled the flow of immigrants with and without watering stations. Their conclusion was that establishing watering stations would most likely not help the plight of the immigrants based on the proposed locations. This activity took two weeks to complete.

A second ArcView project that he and his students completed was researching and mapping the flow of goods and people at six border crossings between in Arizona and Sonora. Their contribution to this electronic atlas (eAtlas) can be viewed at http://victoria.ciad.mx/sonar_e-atlas/ His class was invited to participate in this project by one of the sponsoring agencies. His students did some research into specific economic indicators and created ArcView maps based on their research. The data included things such as the flow of goods and people at six border crossings between Arizona and Sonora. The class's contribution was part of a larger economic database of information. Using ArcView they created a map with themes that displayed this data.

Using Scion Image, his students photographed a ball dropping and used the software tool's measurement capability to determine the speed of gravity. Jim had discussed a similar exercise completed by one of the VISM participants during the summer workshop. He adapted that into an activity that required two 90 minute class periods to complete—one period to take the photograph and do the measurements and a second period spent analyzing the data.

Jim's students also completed one assignment using the molecular visualization software. First they created RASMOL model of a number of different inorganic solid structures which they observed the shape of and predict the polarity. This was a single 90 minute period lab activity. To successfully complete the activity, the teacher had to be able to find and download the necessary .pdb files from Internet sources, one of the descriptors of the adapt level of using this tool.

It is important to note that this teacher was a very accomplished user of Scion Image and/or NIH Image user as well as ArcView GIS user prior to the VISM workshop. He had extensive experience leading workshops and developing curricular materials using all of these tools with teachers around the country. He certainly was using these tools at the innovate level with students before Project VISM. He is the kind of teacher that Project VISM was designed for: someone who had successfully integrated at least one tool into his classroom practice and was now ready to learn a few new tools. He was one of the few teachers who proposed an integrated project that combined the use of several tools in his presentation at the conclusion of the summer workshop. He represents an exemplary use of scientific visualization tools, and Project VISM was only a small part of helping in his development in these areas.

In addition to using these tools in his own classroom, he also shared some of these tools with his colleagues as part of his commitment to Project VISM. He demonstrated Scion Image to a few individual teachers for an hour or so. He offered an informal workshop in ArcView GIS for six elementary teachers and worked directly with some of their students on a follow-up project in February. He pointed out that he did not do any of his at own school, where he is viewed less as a science teacher than as a representative of a "school to work" program of which he administers in his building. He is relatively new in this school and as such is perhaps not yet perceived as an accomplished science teacher in the eyes of other teachers there, but based on his work at other schools and in other jobs earlier in his career he is recognized as a capable science teacher in other schools.

Next year he plans to offer further support to his colleagues in using these tools. One of the social studies teachers is very interested in ArcView, and he is also working with a sponsored project that may fund a university student who will try to spread geographic awareness via ArcView GIS by working directly with some teachers in the area. He plans to work with the one other science teacher in the school who is new and seems receptive to using these kinds of tools. He is planning to work with elementary and high school teachers on an individual or cluster workshop basis as the opportunity presents itself.

There are a number of supporting factors in this teachers' exemplary use of visualization tools,. His prior expertise in using two of the tools on a regular basis in his teaching was critical. The professional contacts that he had made outside of the workshop were also important. For example, the eAtlas project happened in his classroom because of his prior contacts with the local university's office for promoting K-12 partnerships. As a teacher he talked about how he sees the relevance of GIS mapping activities in everyday news items and has a strong interest in drawing that into the classroom to help connect scientific learning with current events. The immigration watering station debate was an excellent example of this. When asked to describe how he was able to keep his skills sharp in using these tools, he stated, “To learn the tool, I teach students with the tool.” A prime example of this “learn by teaching” method was the inorganic molecule lab that he did with RASMOL. RASMOL was new tool in his practice this year, and he was determined to use it at least once to improve his confidence in using the tool, so he created one activity and tried it out with his students. This suggests that this “use it with my students or I’ll lose it” attitude that tolerates a fair amount of uncertainty in the first use of the tool is critical to successful use, and is something to encourage in future work with teachers.

When asked to describe the major obstacles he faced in using the tools, this teacher stated succinctly that the lack of teacher time to design activities is the greatest obstacle for him and, in his opinion, for other teachers. All the things he had not accomplished but hoped to involved more time. He had hoped to teach students how to make a simple STELLA model (he had them use his STELLA model, but did not get as far as having them design their own). As a very capable ArcView GIS user, he had also hoped to get to use some of the more advanced tools such as Spatial Analyst and the 3D analyst extensions.

For this experienced and successful user of scientific visualization tools, Project VISM was most importantly a place to develop his teaching craft knowledge as well as learn two new tools. Even as an accomplished computer user, he found himself gaining increased confidence with the computers, with the tools, and encouragement from the other teachers to use it in the classroom. Participating in Project VISM with the other participants made him think “Yes, I can do this with my students.” When asked what his rationale would be for using the tools with students, he was very clear in his response: they are engaging for students. “It involves them and puts them into the problem. These tools allow for activities that can be adapted to current events so easily–in some cases right from this week’s headlines.”

Teachers two and three, more typical examples of adopting and adapting the VISM tools

Bill and Greg are both teachers who participated in the pilot version of the VISM workshop offered in the summer of 2000. That first session lasted four weeks instead of three, and had only ten participants. Both teachers were interviewed following their second year of using the VISM tools in their classroom. One interview was by phone, while the other was face to face.

If Jim might be described as an unusually advanced user of scientific visualization tools prior to the workshop, Bill and Greg are more typical examples of adopting and adapting the VISM tools into their teaching practice. Bill has demonstrated the use of three of the four tools to his students, but has not yet been able to do any student activities or projects with his students, in part because of high stakes testing in his state that has reduced the number of project-oriented activities that he does with his students. He is anticipating doing more with the tools in the coming year as he is teaching more upper division classes. Greg has been able to design an elective course around the use of the geospatial analysis tool, and thus has completed projects that use ArcView GIS projects with more than 40 students. These students have attended a statewide GIS conference, and he is in the process of considering offering this course online so that more high school students in the region can participate. Not surprisingly, Greg is seeking out further training in learning how to use ArcView as a result of this success. He also adopted one image processing activity into his 9th grade computer applications class as part of a population sampling activity.

Thus Bill might be described as having initially adopted three of the tools into his practice, but only at the level of using them as demonstrations with his students. Greg has adapted some ArcView GIS activities from a published text (Getting to Know ArcView 8.0, 2001) which he purchased following the VISM workshop. With further development he will certainly be at the level of innovating with the tool. Since his students are already creating their own projects based on materials not supplied in the VISM workshop, one might say that he is already at the innovate level at present, but when interviewed Greg emphasized how much more he wants to learn about using the tool so he can better support the student projects.

Both Greg and Bill have shown the VISM tools to colleagues on an informal basis, both individually and in small groups. They planned to give a workshop at a regional conference, but the conference itself was cancelled due to recent budget cutbacks which greatly reduced the number of teachers who would be attending.

There are several factors that have supported Bill's continued use of the VISM tools in the two years since the workshop. The fact that he was going to be giving a workshop to other teachers has meant that he has made a concerted effort to keep his own skills up by practicing with the tools on his own time and for class demonstrations. He remains optimistic about future use of the tools with students: "Looking down the road, knowing [these tools], more opportunities will come up to use them in different ways, especially ArcView."

But he also perceives one very distinct obstacle to using these tools. He stated that there is simply not enough time in beginning courses with the current high stakes testing in place. He notes that his students have been very successful in passing the examinations, as his results are among the best in the area. All but four of his students passed the required exam for the course, and in his state all students must pass 6 such tests total in order to graduate from high school. Thus the successful completion of $1/6^{th}$ of a student's graduation obligations through one course is noteworthy. But Bill, a teacher with over two decades of experience, points out that a number of the projects that he used to do with students (whether with or without technology) have been squeezed out because of time. "The fun stuff is gone. But the academics are tightened up, and it is proving successful with the students."

An example of a project that he no longer does with his students is the layers of the earth cupcake activity. Bill would bake cupcakes with different colors or layers and have students take a core sample of the cupcake with a straw. They would take 4 cores across the top of the cupcake and create a fence diagram. Different cupcakes illustrated different features in the way the earth's layers were formed. The activity generally took two periods, and over the years a number of his students had come back and fondly recalled this activity. But in light of the new demands of the tests, Bill concluded that this lesson was too slow in delivering the necessary content. So instead he now shows the students a picture of a corer and they use online resources to see how to make a fence diagram. They no longer make their own fence diagram, but that is not an item that is on the test.

When asked to describe what role VISM played in his own professional development, he said that it prepared his for the next opportunity that would further develop his knowledge of ArcView GIS, the tool he thinks he will most likely use in the advanced course with his high school students.

Greg also lists a number of supporting factors that helped him employ the tools in his classroom. Most importantly was Getting to Know ArcView 8.0 (2001), the text used in his GIS course, that he purchased following his VISM experience. He was looking for well written materials about how to use ArcView with step by step directions, and this publication provided that. He also cited his administrator's support in getting the ArcView GIS elective course off the ground. Apparently an alumnus of the school was telling Greg's administrator that they should be teaching a course on GIS the day after Greg returned from VISM, ready to make such a proposal. He has also actively continued to seek out professional development opportunities to further develop his GIS skills. He has attended a national ESRI conference. He has taken his 22 students from class to the state conference while a colleague covered his classes. And he has become an unofficial member of the local GIS professional group. He attended another workshop at James Madison University called Great Outdoors, Digital Indoors (GODI) to better develop his GIS skills and their application in a local national park. And he has received data and technical support from a local GIS professional in one of the smaller counties who contacted Greg when he heard from one of Greg's student's parents that he was using ArcView.

Most observers would consider Greg an accomplished GIS user among educators, but he still perceives the biggest obstacle to further use to be his own lack of his own knowledge of the tools. "I am trying to find out how much I need to get out of the way [in supporting student's work in doing ArcView projects in the GIS course]. I found out last year that I needed to be MORE of an information source than I thought I would need to be. So I am improving the base material for the course and will do more formal instruction this year." For other teachers, he believes that the flexibility to try these tools with students is the biggest obstacle. "The [required state learning objectives] are scaring the daylights and creativity out of teachers" he states. Yet Greg points out that he keeps finding other teachers who *are* able to overcome these barriers. "Every school has someone doing more than I ever do with my privileged position" (i.e. teaching at a magnet school with extra resources and more flexible teaching schedule).

Greg's rationale for continuing to use these tools is that the students have found it very current and very appropriate for skills that they want to have. For Greg, the VISM workshop was a place to add new tool skills while collaborating with other teaching professionals who were trying to use these more advanced tools with their students.

Teacher four: VISM tools as a vehicle to learning other tools

Dan was also one of the teachers who participated in the pilot version of the VISM workshop offered in the summer of 2000. Following what was described as a very successful though demanding workshop, the participants headed back to their classrooms expecting to use the VISM tools with their students. During the school year we did not hear a lot from Dan. He did not offer any workshops for the teachers in his school using the VISM tools. When contacted at the end of the first year his tone was apologetic. Despite high hopes to the contrary, he did not use any of the VISM tools during the school year with his students. In terms of the VISM matrix, Dan had not adopted any of the tools into his teaching practice.

In the course of the interview, he happened to mention something about some probeware he had begun to use in his classroom. When asked to describe a project that he had done with students using this tool, he described a physics lab that used the probeware to make a direct measurement of the speed of sound. This was one of the published activities that came with the probeware, he explained, and he believed his students worked hard to learn how to read the real time graphical output. He described a second lab, where they tried rolling a cart down a plane. The task for the students was to figure out what happened with the cart and be able to interpret the event as the force sensor would do so. This activity "was entirely different conceptually to what we would've done without the computer."

In fact he found his experience in learning the VISM tools invaluable in using these new tools. In a written summary of the phone conversation, he talked about the "unintended consequences" of VISM and similar programs. He described the positive outcomes from the experience as follows:

- Since a full complement of computer stations had just recently been installed in my classroom, along with lab-interface kits (probes and software) for Windows computers, my first priority upon returning to school in the Fall was to get that material up and running in the classroom. This was a much more labor-intensive and time-consuming process than I had predicted, but it was ultimately successful (i.e., lab exercises were being performed by my students on a regular basis). I would also say that the PC/Windows skills that I developed at VISM were vital to this success…[Prior to the workshop] my own [computer] skill level was really very low. So, unintended consequence #1: my VISM experience provided excellent training for the use of hardware/software in my physics classroom.
- I used two software packages in my Astronomy class…[one of which] proved to be excellent. The activities were clearly based on challenging problems that have been solved by astronomers, by first collecting data through a telescope and then analyzing the data. The software allows the student to use the computer monitor as a telescope simulator, and then nudges the students through a variety of steps involving both image-analysis and mathematical manipulation. I didn't acquire this program until November, but I was able to use it in the classroom almost immediately, again due to the expertise gained through working with the VISM materials…[the] value [of this software] in the classroom was in large measure due to the quality of the images on the computer screen, and the ease with which students could make measurements on those images.

The VISM experience helped Dan upgrade his knowledge of computers. He also learned several tools, none of which he used, but this learning experience made him more confident when the next tool came into his classroom. Furthermore, he had a clear eye for the value of visualization for his students learning, something discussed often in the VISM project. In the interview he stated:

> Visualization tools allow students a better understanding of key concepts that you have traditionally taught. Kids are so adept at graphical stuff all the time. They are ready to use the tools and make inferences from them.

Dan found the VISM experience sufficiently valuable that he wrote about it in his recertfication portfolio that he submitted to the state to demonstrate his professional growth for licensure renewal. He described how his participation in Project VISM helped him meet goals from his individual growth plan such as developing links to science educators, developing computer-based curricula, and developing techniques that encourage girls in science. He also stated that his VISM experience made him an advocate for using technological tools in the sciences:

> …the experience of spending one month with several educators who have already made great strides in using computer technology in their classrooms has given me the knowledge and confidence to go to our administration and school board and fight for a significantly increased investment in technology. This has become an equity issue: first, in providing an alternative mode of learning that is more successful and more appealing to some students; and second, in helping to prevent a situation in which our students are not keeping up with those in other districts.

When asked to what were the major obstacles to using the VISM tools in his classroom, he pointed out that these more advanced tools were harder to learn. And in using the probeware in physics and the astronomy software, the curriculum connections were clearer. "I open the manual [for the probeware or astronomy software] and I see traditional physics stuff that I know. It is just that this format is different. I am really at home with the conceptual stuff." His experience coincides with findings from the ACOT project that teachers first adopt technology in a way that closely resemble their work without technology. The probeware software came with well-written labs that resembled traditional physics labs but used new tools. In the VISM workshop teachers developed their own projects based on the new things they had learned using the tools, which is a more challenging task. Furthermore, the activities from the VISM workshop did not transfer directly to Dan's classroom. Thus the obstacles to using the VISM tools—the need to develop his own activities and the lack of preparation time to maintain his knowledge of these tools–were not present in using the probeware and the astronomy software. Table 2 provides a summary of the initial findings of all four of the teachers described above.

Discussion

The efforts of the four teachers described above span a range of implementation possibilities. Each of these teachers both brought and took something different from the summer workshops and then proceeded to their own unique implementation in their classrooms. From the nearly all-inclusive implementation of Jim to the more targeted uses of Bill and Greg to Dan's application of the techniques to a different tool, each teacher explored the constraints of their classroom and found the use that best suited them at the time. One thing to bear in mind is that the discussion above represents a brief history and a current snapshot and does not really capture the evolution of this dynamic process. A return to each of these classrooms two years hence would yield different and interesting variations on the theme of data visualization tools in the curriculum.

These four teachers work in three different states and in very different schools, yet the commonalities of their barriers echo comments we hear from teachers across the country. Especially in implementing advanced tools, there is a need to have blocks of planning time to develop skill with the tool and to be able to think through the curricular uses of the tool with students. Absent this time, teachers will struggle to do the creative work that leads to the innovate stage

An ongoing challenge of this kind of work is successfully disseminating the work of a teacher like Jim to other teachers in a form that they could readily use in their classroom. By its nature, innovative work that is grounded in local issues is idiosyncratic and difficult to transport to other areas. Abstracting the lessons to more general, less local issues seems to somehow denature them. This is an unresolved, but very important problem in trying to take advantage of the work of creative teachers and share it with their colleagues across the country.

One interesting point that emerges from these stories is the role of high-stakes testing in constraining innovation and limiting the use of these tools (c.f. Bill). This has been reported informally by other participants in the VISM workshops and it poses somewhat of a paradox – do we better prepare students for the world by introducing them to the tools and ideas that await them or do we focus on "drill and practice" style mastery of facts that might better prepare them for the tests. In discussing this with Bill, he expressed both an enthusiasm for the greater academic seriousness that can accompany these tests, yet a concern about the limits of assessment in capturing all that students may learn through richer sorts of student projects.

Tool	**Teacher one (Jim)**	**Teacher two (Greg)**	**Teacher three (Bill)**	**Teacher four (Dan)**
Image processing *NIH Image/ Scion Image*	Innovate Physics Image project — photographing and dropping a ball and determining acceleration rate of gravity. Adapted from a VISM participant. -90 minutes period to do -90 minute period to analyze	Adopt Completed Travel USA activity with 9^{th} grade computer apps course— part of a population sampling activity. 1 period activity	Adopt Demonstrated one NIH Image activity to students No student activities or projects. 1 period activity	None
Geospatial Analysis *ArcView GIS*	Innovate Used from first week of school to last week in Environmental Science course. Class research question: Should we put water out or not for illegal immigrants to reduce mortality rates? Plotted paths where illegal immigrants could come across on an image of the southwest. -2 week activity Students researched and created ArcView themes of economic indicators for 6 border crossings between AZ and Sonora. Helped build an economic database of information. Published to website: http://victoria.ciad.mx/sonar_e-atlas/ -8 week project	Adapt $11^{th}/12^{th}$ grade elective course on GIS with 22 students each time. Students completed GIS projects from the ESRI text "Getting to Know ArcView 8.0" text Multi-week projects– course focuses on the use of the tool in mapping	Adopt Demonstrated one GIS activity re the distribution of volcanoes. No student activities or projects. 1 period activity	None
Molecular Visualization *RASMOL* and *Chemscape Chime*	Adapt RASMOL activity: RASMOL model of a number of different inorganic solid structures which they then observe the shape of and predict the polarity. 1 period lab activity (90 minutes)	None	Adopt Demostrated 3D capabilities of visualization software. No student activities or projects. 1 period activity	None
Systems modeling *STELLA*	Adopt Teacher created STELLA model of immigration rates with or without "watering holes" used by group to answer research question. 1 period activity	None	None	None
Comments	Innovate level in NIH Image/ Scion Image and ArcView prior to VISM	Pursuing further instruction in ArcVIEW GIS after VISM	Intends to begin doing activities/projects with students in more advanced courses next year	Adopted probeware/ astronomy software instead of VISM tools

Table 2. A summary of levels of use of the VISM tools by each of the teachers

One other limitation of the study thus far is that all four cases are male teachers with more than fifteen years of teaching experience. This was also a challenge faced by Project VISM, as the applicant pool initially tended to be white males with many years of teaching experience. By changing some of the format of the workshop and by recruiting more broadly, the project was able to recruit younger teachers, women teachers, and more teachers who were members of ethnic minority groups. We expect future case studies to reflect the greater diversity of the Project VISM participants that took part in subsequent session of Project VISM.

As part of our work with the instructors and participants Project VISM, we have developed some refinements to the ACOT model that we think are pertinent to the kinds of more advanced tools we are asking teachers to use with their students. The current ACOT model bases each of the stages on a given level of competency with the technological tool, and describes their development in using that tool with their students. But in working with scientific visualization tools with teachers we have noticed that this competency really has three component parts. Those three parts are:

- Competency with the software **tool**
- Competency with the scientific **data** that the tool uses
- Competency with the **pedagogical content knowledge** needed to teach curricular content using the tool

We believe that these three components help determine a teacher's ability to move forward into the next stage of development in using a given tool. For example, imagine a teacher has just attended a workshop and learned how to use NIH Image, an image processing tool, and also has some images and classroom-ready activities prepared for their first efforts at using this tool with their students. Here is a teacher ready to *adopt* image processing into her classroom because she has the capabilities to use the tool (NIH Image), has the necessary data (the images) and has a first "cut" at knowing how to "chunk" this activity to achieve particular educational objectives that are in her curriculum (classroom-ready activity she received or created at the workshop). These same three components come into play as that teacher moves to the *adapt* level of development. For example, in the second year that same teacher uses the activity, she might significantly "tweak" the materials and/or the approach she uses to teach the same material. One might argue that this "tweaking" is a prerequisite for even first time use of the activity (Harris 1998), but the kind of changes we are suggesting here are more substantive and often require teaching the material once to "kick the bugs out" of a given lesson or project. In addition, tweaking the activity might also involve learning some new aspect of the software tool, or refining one's approach to teaching the tool to students. Then in the *innovate* stage many teachers begin to bring in their own (and often locally more meaningful) data with their students. In NIH Image that might mean learning how to bring in a JPEG file from a digital camera at the best level of resolution, or how to find uncompressed TIFF files at a NASA website and download them onto their local computer from the World Wide Web. Moving to the innovate stage is often dependent on learning how to bring in new data sources. Or it might be dependent on certain kinds of new pedagogical content knowledge, such as how to better enable student-initiated projects in the context of increasingly high stakes testing and standards-driven curriculum. Thus significant development in one of these three components is consistently linked with moving forward to the next stage of development for many teachers.

Finally, we would like to raise some questions about the current prevailing wisdom regarding teacher professional development, which advocates site-based, curriculum-specific professional development efforts with significant on-site follow-up. Project VISM was a university-based program with materials that had only general curriculum connections and with no significant on-site follow-up component. We are not so much arguing against the former approach, though we do have serious questions about the long-term sustainability and scalability of many of the projects that feature such an approach. But we think there is still room for excellent university-based programs where teachers learn a great deal personally and are still charged with a great deal of responsibility for taking this new learning and applying it to their own practice. The emerging consensus that effective professional development efforts for teacher should resemble corporate-style training sessions may not give sufficient credit to the intrinsic motivation that drives successful educators to conduct what is in effect their own program of professional development, one that is unique to each professional. Stated differently, we want to continue in our interviews with the teachers in this project to attend to the fundamentally constructivist nature of teacher learning.

References:

Baker, T.R. & Case, S.B. (2000). Let GIS be your guide. *Science Teacher* 67 (7), 24-26.

Charles, M.T. (2001). Evaluation Report of Project VISM: Visualization in Science and Mathematics, Summer Workshop--Year One. Unpublished report to the National Science Foundation.

Charles, M.T. (2002). Evaluation Report of Project VISM: Visualization in Science and Mathematics, Summer Workshop--Year Two. Unpublished report to the National Science Foundation.

Charles, M.T. & Kolvoord, R.A. (2001) Teacher's stages of development in using visualization tools for inquiry-based science: The case of Project VISM (2001). Proceedings of SITE 2001. Charlottesville, VA: Association for the Advancement of Computing in Education.

Geographic Information Systems in the Classroom (2000). *Educator's Guide to Computers in the Classroom*, 1, 1-5.

Getting to Know ArcView GIS 8.0 (2001) Editors of ESRI Press.

Gordin, D.N. & Pea, R.D. (1995). Prospects for scientific visualization as an educational technology. *The Journal of the Learning Sciences*, 4 (3), 249-279.

Greenberg, R.; Kolvoord, R.A.; Magisos, M.; Strom, R.G.; and Croft, S. (1993). Image Processing for Teaching. *Journal of Science Education and Technology*. 2,14-18.

Harris, J. (1998). *Virtual Architecture: Designing and Directing Curriculum-Based Telecomputing*. Eugene, OR: International Society for Technology in Education. Accessed at http://ccwf.cc.utexas.edu/~jbharris/Virtual-Architecture

Jonassen, D.H. (2000). Systems modeling as mindtools. In *Computers as Mindtools for Schools.* Columbus, Ohio: Merrill, Prentice Hall.

Malinowski, R., Klevickis, C., Kolvoord, R. (2001) Come see the molecules—using 3-D modeling programs to learn chemistry. *Learning and Leading with Technology*, 29 (4) 36-41, 61. Accessed at http://www.iste.org/L&L/archive.html

Project VISM (2000). Accessed at http://www.isat.jmu.edu/common/projects/VISM/

Sandholtz, J.H.; Ringstaff, C.; Dwyer, D.C. (1997). *Teaching with technology: Creating student-centered classrooms.* New York: Teachers College Press.

Thomas, D.A.; Johnson, K.; and Stevenson, S. (1996). Integrated mathematics, science, and technology: An introduction to scientific visualization. *Journal of Computers in Mathematics and Science Teaching*. 12 (3), 267-294.

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