# Using Visualization Tools for Inquiry-Based Science: A Longitudinal Study of Teacher's Stages of Development

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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. But there is little data that describes how successful teachers are in using these tools with their students in the chronically under supported technological settings of K-12 education. This paper uses a stages of adoption model to describe teacher progress in utilizing four visualization tools to facilitate project-based scientific inquiry. Summary data are presented from twenty-five participants in this longitudinal study based on follow-up questionnaires and interviews that describe how some teachers have begun to integrate these relatively advanced scientific visualization tools into their teaching practice.

Scientific visualization tools offer a rich use of the more powerful computers that are becoming more and more plentiful in schools 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 & Case 2000; Greenberg et al. 1993; Gordin & Pea 1995; Jonassen 2000; Thomas, Johnson, and Stevenson, 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 of these more advanced tools, 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. The approach taken in Project VISM was to provide participants with a relatively brief look at several different tools versus an extended exploration of one tool.

*The VISM matrix*

This paper examines the question of teacher success in incorporating the scientific visualization tools into their teaching practice following a very successful three week summer workshop in which the teachers demonstrated their ability to use at least one of the tools to create a curriculum-related project. It was posited that teachers would go through stages in adopting these new and relatively advanced technological tools into their own practice. The Apple Classroom of Tomorrow (ACOT) model describes four stages teachers can progress through in moving new technological tools into their practice: entry, adoption, adaptation, and innovation (Sandholtz et al. 1997). The VISM matrix (Appendix A or Charles & Kolvoord 2001) was developed based on this model. It describes each of these four stages in specific terms for each of the four tools that were taught in the VISM workshop. The four tools were:

- Image processing using Image J, NIH Image or Scion Image software
- Geospatial analysis using ArcView GIS (Geographic Information Systems) software
- Molecular visualization using RASMOL and Chemscape Chime software
- Systems modeling simulations using STELLA software

The matrix was developed to assist in describing the way that teachers use these tools with students in their classrooms at the adopt, adapt, and innovate level, and how that use evolves over time. We believe that this matrix could be adapted to describe the integration of many of the more advanced and discipline specific software tools, and then used to track the stages of teacher development in using these tools.

*Participants*

The one hundred and eighteen participants in Project VISM were mostly middle and high school science teachers with some mathematics teachers. There were also a couple of elementary teachers and a few from higher education among the participants. Generally the participants were well-educated career teachers in stable work assignments who rated themselves as having good computer skills and good computer access at their schools. The average VISM participant was over forty-five years of age, had twenty years of teaching experience, with more than ten years in their current position. More than two-thirds had a master's degree or higher. The group was largely Caucasian, and two-thirds of the group were males.

The twenty-five participants who have been interviewed or completed the questionnaire were mostly high school teachers (19 of the 25). Most of them taught science (18 of the 25). There is a notable cluster of earth science/physics/GIS teachers (15 of the 25). They reported that they work with an average of just under 150 students per week, so they are generally from larger high schools or middle schools with many classes and larger class sizes.

*Method*

This inquiry summarizes current findings from twenty-five of the one hundred and eighteen participants in Project VISM as they implemented scientific visualization tools in their teaching practice in the years following the workshop. Descriptions are the self-report data of the teachers. In subsequent studies we plan to collect data from a greater percentage of the participants as well as continuing to revisit the work of selected participants in the coming years.

The data sources for this study were interview protocols for a selected group of participants and a ten question "follow-on" questionnaire administered to twenty participants who chose to attend a follow-up weekend workshop (See Appendix B). The interviews were carried out first, with eight participants. Teachers selected for the initial set of interviews were chosen as a sample of interest—in our follow-up discussions with them there seemed to be intriguing things happening in their work with students following the workshop, and they seemed to represent a range of use of the tools, from not at all through adopt, adapt, and innovate. The interviews were based on a structured set of questions drafted in advance, but also include open-ended questions for more in-depth follow-up. We have written previously about these participants as brief case studies (Charles & Kolvoord 2003) that demonstrate that the VISM matrix was useful in describing teacher progress in using these tools in classrooms.

Following these case studies, the questionnaire was developed for participants in a follow-on weekend workshop that some of the participants voluntarily took part in one to three years following their initial VISM workshop experience. Three of the participants in this follow-on weekend workshop had also been interviewed in prior years. Thus the total number of participants reported on for these findings is 25. The central question for both the interview and the questionnaire was for the participants to describe one project they had undertaken with their students that used one of the tools they learned in the workshop. The three main questions for the questionnaire were:

- Briefly describe 1 or 2 projects you carried out last year with your students using one of these visualization tools.
- 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.

Both the interviews and the questionnaires and were summarized by the investigator. Each participant was placed on the VISM matrix based on their responses, and their comments were coded and categorized using constant comparative analysis. Member checks were performed with those who were interviewed.

*Results*

Table 1 summarizes the level at which the different teachers used the VISM tools. It should be noted that the number of responses exceeds the number of participants because many of them are using more than one tool in their classroom. The participants self rating could also be confirmed by reading their description of a project that they completed with their students using the VISM tools. Over forty percent of the participant responses described using at least one of the VISM tools at the adopt level. Half of the uses were at the level of having only done one activity with students—a very low level of use. Nearly 42% of the participant responses described using at least one of the tools at the innovate level, a very high level of use. The ACOT stages of adoption model which is the basis for the VISM matrix suggested that it often takes three years to move to the innovate level, but our participants used these tools at the innovate level from their first year of use.

| | *Adopt* | | *Adapt* | *Innovate* | *None* | *Totals* | *%* |
|---|---|---|---|---|---|---|---|
| **How did you use the tools with your own students?** | used an activity | used several activities | modified an activity | create own activity | Not yet | | |
| Image processing (Image J/NIH Image/Scion Image) | 1 | 5 | 2 | 5 | | *13* | 38.2% |
| Geospatial analysis (ArcView) | 3 | 2 | 1 | 8 | | *14* | 41.2% |
| Simulation (STELLA) | 2 | 1 | | 3 | | *6* | 17.6% |
| Molecular visualization (RASMOL/Chemscape Chime) | 3 | 1 | | 2 | | *6* | 17.6% |
| | *9* | *9* | *3* | *18* | *4* | *43* | |
| | *20.9%* | *20.9%* | *7.0%* | *41.9%* | *9.3%* | *100.0%* | |

**Table 1**: Using the VISM tools at the adopt, adapt, or innovate levels

Very few of the teachers (only 7 percent) used any of the tools at the adapt level. Teachers either used the activities from the workshops with little modification or they created their own activities. In some cases those “innovate level” activites that they created were based on projects that they started while doing the VISM workshop. But more often than not they were activities that “emerged” from their teaching during the school year.

Four of the participants reported not using any of the tools at all. In one case, the participant was not in a classroom any longer, though she had conducted workshops to show these tools to other teachers. Another participant had a teaching assignment change and did not have time to develop any new applications of the VISM tools in her new assignment. Another teacher who reported no use of the VISM tools reported extensive use of probeware tools, and credited his VISM experience for giving him the technical expertise to use the other tools.

The participant responses also indicated that the image processing tools (Image J/NIH Image/Scion Image) and the geospatial analysis tools (ArcView) were the ones most used by the participants. It should be noted that a number of participants came to the original VISM workshops with previous experience using the image processing tools and many were already at the innovate level prior to taking the VISM workshop. The simulation (STELLA) and molecular visualization (RASMOL/Chemscape Chime) were used much less by the participants.

*Sample Projects*

The participants were asked to describe the kinds of projects they carried out with their students that used VISM tools. Here are a few of the projects that exemplify the range of uses from adopt to adapt to innovate. One teacher described a high school astronomy activity using image processing. The students calculated the rotation of the sun using sunspot data for one week. They also did this on paper using a solar telescope. Then they measured the change in size of sunspots and developed conclusions about sunspot life cycle. This is an example of an activity at the innovate level.

Another participant described adapting an existing high school image processing anatomy activity from some published materials. This teacher rewrote the MRI head stack activity from NIH Image into Image J so that students could complete the activity using this newer version of the image processing software. This was an example of an activity at the adapt level.

Using the geospatial analysis tool, another participant created an activity for his 9th grade general science class. The students mapped ground level ozone data collected at about 25 sites across northern and central New Jersey. They had to create Excel files, import databases into Arcview and create their own basemaps by adding relevant themes. This is an example of using ArcView at the innovate level.

Another participant adopted a GIS lesson that he was able to figure out based on his work in Project VISM. In an 11th/12th grade Geosystems course, he used two ArcView projects from the book *GIS Lesson: Virginia Physiography*. This lesson included PowerPoint presentations with pictures, maps, topographic maps (3-D) on the five physical Virginia providences: coastal plain, piedmont, blue ridge, valley and ridge, Appalachian plateau. He stated:

> My students really got into the ArcView lesson plan [with self-guided instructions and graphic illustrations] that got my students to learn about powerful tools of inquiry, investigation and learning--about their own state that they know so embarassingly little about. This ArcView lesson was a powerful preparation for Virginia's Standards of Learning (SOL) high stakes exams. Students were better prepared to answer the SOL questions about Virginia!

This was a very complex project, but it is an example of using the tool at the adopt level in the sense that the teacher simply used the lesson from this GIS text. However it is important to note that the teacher purchased thse materials apart from the VISM workshop—this was not an activity that the participants learned in the workshop but instead one that the teacher located on his own and adopted into his teaching.

One of the participants worked with two calculus teachers and their classes to address related rate problems using STELLA simulation software. The calculus teacher then used activities from a resource book published by High Performance Systems (the publishers of STELLA). This is again an example of using an activity at the adopt level, but with the caveat that the teacher doing the activity did not actually attend the VISM workshop but instead learned the tool informally from a colleague and then supported that learning with quality curricular materials prepared by the program publisher.

A middle school science teacher described using the molecular visualization tool at the adopt level.. He had students view RASMOL models to better visualize the structure of molecules, to count atoms in molecules. and to observe molecules in 3-D.

*Changes in their skills in using the VISM tools*

The participants were also asked to rate how their skills with the four tools had changed since the summer workshop. This data was collected most reliably for the twenty questionnaire respondents, and thus the table summarizes these twenty participants responses (see Table 2). Interestingly, nearly half of the participants (46 %) reported either a "4" or a "5" on the five-point scale of confidence. This is surprising because Project VISM really did not provide any active user support following the workshop. These participants reported further developing their own skills following the workshop through further training courses, or by purchasing curricular materials, or by succesfully completing tutorials online or on CD that accompanied the software, or by simply practicing some of the same activities that they learned in the workshop. Fully 55% of the participants listed engaging in some sort of professional development activity related to developing their skills in using the VISM tools, but none of those opportuntities were provided by Project VISM itself. More than 75% rated their abilities with the tool as either holding steady or improving, all based on their own initiative in continuing to work with the tools. We note that the greatest improveement was in learning more about ArcView. ESRI, the publisher of that program, has an extensive online library of tutorial information for users, and there are ArcView user groups in the larger professional community.

| **Were there any changes in your abilities with each of the tools after this year?** | less competent | | | | More competent | *total* | |
|---|---|---|---|---|---|---|---|
| □ | 1 | 2 | 3 | 4 | 5 | | |
| ArcView | *1* | *2* | *5* | *2* | *8* | 18 | ***3.8*** |
| NIH Image | *3* | *1* | *5* | *6* | *3* | 18 | ***3.3*** |
| STELLA | *4* | *2* | *4* | *3* | *4* | 17 | ***3.1*** |
| RASMOL/Chemscape Chime | *4* | *2* | *4* | *5* | *1* | 16 | ***2.8*** |
| □ | ***12*** | ***7*** | ***18*** | ***16*** | ***16*** | 69 | ***3.2*** |
| | 17% | 10% | 26% | 23 % | 23% | | |

**Table 2**: Changes in the participants abilities to use the VISM tools.

This is not to say that there was not attrition in their use of the VISM tools. Fully one quarter of the responses indicate a decline in their skills in using these more advanced tools. Participants also reported some frustration in trying to further develop their skills in using these tools by simply practicing some of the activities from the workshop independently.

*Obstacles to using the VISM tools in their classrooms*

The participants also rated the obstacles that they encountered in trying to use these tools in their classroom (see Table 3). This question was most reliably put to the group that answered the questionnaire so this data summarizes the responses of only twenty participants. The lack of adequate preparation time was their greatest concern, followed by the lack of space in a crowded curriculum, a lack of teacher knowledge of the tools, and a lack of adequate hardware/software. Student difficulty in learning the tools was the lest of their concerns. We asked the participants this same question both before and after their initial three week Project VISM workshop. Further analysis needs to be conducted with this data to see if there has been significant change in their perception of obstacles over time.

| | not an obstacle | | | | serious obstacle | | |
|---|---|---|---|---|---|---|---|
| | *1* | *2* | *3* | *4* | *5* | Responses | Average |
| Lack of adequate teacher preparation time to prepare activities | *2* | *2* | *5* | *7* | *3* | 19 | 3.4 |
| Lack of space in a crowded curriculum to do projects that use these tools | *3* | *2* | *8* | *2* | *3* | 18 | 3.0 |
| Lack of teacher knowledge of these software tools | *3* | *4* | *5* | *4* | *3* | 19 | 3.0 |
| Lack of adequate hardware/software | *4* | *4* | *3* | *3* | *4* | 18 | 2.9 |
| Incompatibility of these tools with district's stated educational objectives | *4* | *7* | *1* | *2* | *4* | 18 | 2.7 |
| Lack of well-designed curriculum-based materials using these tools | *6* | *1* | *7* | *3* | *0* | 17 | 2.4 |
| Relating the use of these tools to increasing student achievement scores | *5* | *6* | *3* | *3* | *1* | 18 | 2.4 |
| Student difficulty learning the tools | *2* | *11* | *3* | *1* | *0* | 17 | 2.2 |

Table 3: Participants ratings of the obstacles they face in implementing these tools

*Brief case studies*

We include a short summary of some of our participants as another way to describe our findings. Each of these cases was drawn from the interview data. One of our four cases was working at the innovate level with two of the tools prior to the workshop. A year following the workshop he had further developed his skills at innovating with those tools. Of the two tools that were new to him in the workshop, he is using one of them at the adopt level and the other at the adapt level. He is the one teacher who was able to use multiple tools as part of a single student project.

Our second two cases can both be described as having successfully moved one or more of the tools into their teaching practice. One of the teachers adopted the image processing tool into one of his courses, using it for a particular activity. He has also designed an entire course around one of the other tools, which he is using at the adapt or arguably the innovate level. He is actively seeking out further training in this tool. The other two tools he has not used in his classroom, nor does he expect to. The second teacher in this group has used three of the four tools with his students, but only as a part of teacher demonstrations. He is looking forward to using them as part of student projects next year as he is teaching some upper division high school classes that would better use these advanced tools. He does not expect to use the fourth tool with his students.

Our final case has not used any of the four tools taught in Project VISM. He instead found that learning the VISM tools became a vehicle that helped him learn different tools that became available in his classroom following his return from the workshop. Those tools are probeware and astronomy simulation software, both of which he is using in technology enhanced lab experiences with his students.

*Discussion*

The efforts of the many 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 one teacher to the more targeted uses of another teacher to a third teascher'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.

As part of our work with the instructors and participants of 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.

Just what is the nature of effective professional development experiences for teachers that use advanced technological tools? We notice that in many of the discussions of professional development there is a good deal of discussion about "building capacity" in the system and "ramping up technological change." To our ears these sound like production metaphors. And while they may be helpful in reminding us to strive to create "sustainable" professional development efforts, they may also miss the fundamentally constructivist nature of teacher learning. It is striking to us that over half of our participants report actively pursuing further professional development in the use of these tools, and that none of this came from the project. Teachers actively pursue a program of professional development that is their own particular construction even if it is not a part of a recognized district or academic program.

The teachers in this nationwide project 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 more innovative teachers 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. 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 one of the interviews, one participant 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.

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 discussions with the teachers in this project to attend to the fundamentally constructivist nature of teacher learning.

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