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Students Creating Their Own Thinking-Learning Contexts

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Abstract

This paper focuses on two high school students and their thoughts and feelings as they engaged in a topic of their choosing during a two-month summer action research program. Their high school astronomy teacher monitored their choice of topic and progress. The students engaged in authentic tasks and materials couched in problem-oriented formats within meaningful learning contexts designed to foster thinking and learning. These students worked as a team, but pursued individual paths of inquiry using critical and imaginative thinking, and engaged in social and solitary contexts that involved them in writing, intervening, and reflecting on ideas gleaned from conversations and readings (electronic and conventional) with a university educator and an astronomer/educator during their self-directed case-based research. The process engaged students in formal skills such as written communication, literacy, logic, and calculation using an innovative electronic interactive network. Evaluations of timed writings, concept maps, notebook entries, and vee diagrams are presented and discussed.

Students Creating Their Own Thinking-Learning Contexts

How students create their own thinking-learning contexts when confronted with authentic problem-oriented tasks is an important issue that influences instruction and learning. Thinking-learning contexts are those mental models (conceptual frameworks) that students invoke when confronted with problem-oriented tasks that go beyond memorizing and compartmentalizing information (Alvarez, 1993).

This paper details how *self-directed* case-based research and instruction together with collaborative interactions with teachers, students, scientists, and university educators using metacognitive tools (e.g., electronic journals, interactive concept maps, and interactive vee diagrams), and innovative technology promotes meaningful learning in ways that differ from conventional educational settings. Teachers, researchers, and students mutually define research problems. Students engage in "real-life" self-directed case research. Together, this collaboration informs practice for students, teachers, and researchers. Within this negotiated learning environment educational processes and outcomes are achieved that meet both local and national contexts for achieving meaningful learner-centered science, mathematics, and literacy goals (e.g., American Association for the Advancement of Science, 1989; International Reading Association, 1992; National Science and Technology Council, 1995; Science Council of Canada, 1984; Royal Society, 1985; NASA's Education Program, 1999-2003).

Theoretical Framework

Gowin's (1981) theory of educating, Ausubel's (1963, 1968) cognitive theory of meaningful reception learning, an emphasis on teachers and students becoming

"communities of thinkers" (Alvarez, 1996, 1997a,b,c), and an action research constructivist epistemology provide the philosophical and theoretical background upon which this investigation was designed and through which the results were interpreted. Gowin's theory of educating focuses on the educative event and its related concepts and facts. This theory is helpful in classifying the relevant aspects of the educative event. In an educative event, teachers and learners share meanings and feelings so as to bring about a change in the human experience. This theory stresses the centrality of the learner's experience in educating. In order for meaningful learning to occur in Ausubel's theory three conditions need to be considered: (1) materials need to be concept rich, with clear relationships; (2) the learner needs to have relevant prior knowledge and experience with the concepts and propositions that are presented in the new materials; and, (3) learners need to have a meaningful learning set - a disposition to link new concepts, propositions, and examples to prior knowledge and experience (see Novak, 1998). A community of thinkers is defined as an active group of students and teachers striving to learn more about a discipline by engaging in the processes of critical thinking (thinking about thinking in ways to bring about change in one’s experience) and imaginative thinking (exploring future possibilities with existing ideas, Alvarez, 1996, 1997b). The notion presented by this theoretical framework enables both students and practitioners to become better informed and knowledgeable about practices that enhance conceptual learning and meaningful understanding.

To better understand how teachers, researchers, and students activate and build upon existing knowledge it is necessary to study the ways schema is activated and new knowledge is constructed. Schema (plural schemata) is a mental construction of an

event, object, or an individual characteristic that can be fragmentary, inaccurate, or inconsistent. It is based upon a belief that can be applied to either physical systems or semantic meanings depicted in a text. When reading a text, the text can be seen as a series of acquisition statements within a given topic or subtopic. The notion of schema theory is that a person can comprehend a text when it is congruent with his or her belief system. Educators and researchers have suggested numerous instructional strategies to help students activate and use prior knowledge to aid comprehension. Yet, schema theory does not explain how readers modify and create new schema when presented with novel information in texts. Because texts are never completely explicit, the reader must rely on preexisting schemata to provide plausible interpretations. There is much evidence to suggest that good and poor readers do not always use schemata appropriately or are unaware of whether the information they are reading is consistent with their existing knowledge (e.g., Bartlett, 1932; Bransford, 1985). Also, there is evidence that students who do not spontaneously use schemata as they read will engage them if given explicit instructions prior to reading (e.g., Ausubel, 1960; Bransford, 1985).

Action research is a paradigm that is grounded in the reality of classroom culture and under the control of teachers. Findings emanating from this type of research investigation inform teachers and guide their practice when formulating lessons and conducting future classroom research projects. Action research is defined as the acting on an event, object, problem, or an idea, by an individual or group directly involved in gathering and studying the information for themselves, and using the results for the purpose of addressing specific problems within a classroom, school, program, organization, or community (Alvarez, 1995). Action research is deliberate and results in

ownership by the participants. The consequences affect participants personally. The *action* is the acting on an event, object, problem, or an idea for the purpose of monitoring and evaluating its course and outcomes. *Research* is a systematic deliberate critical inquiry of an event in order to enlighten one's thinking, learning, and practice. This setting in motion of a strategy for the systematic study of an event that evolves from an idea or problem is the basis on which these investigations are predicated. In this project, the events that are studied take place in an educational setting and the study is conducted by student and teacher researchers in collaboration with university educators and scientists in the areas of earth and space science. This action research strategy is accomplished through a recursive cycle of (1) identifying an idea or problem area, (2) studying it by gathering data, and (3) reflecting on the data in order to make teaching and learning decisions grounded in evidence (see Appendix A - Action Research Strategy, Alvarez, 1995).

The focus of this action research inquiry centered on the research question: RQ1 "How do students create their own thinking-learning contexts using metacogntive tools and electronic communications when they are asked to select a topic of study of their own choosing? Within this realm of inquiry are included the effects of timed writings and their influence on schema activation and knowledge construction.

Method

This study was conducted over a two-month summer session at the Center of Excellence in Information Systems, Tennessee State University. Two students, Bobby Hulan (attending school) and Addie Graham (home schooled), both tenth graders and Bobby's teacher, Terry King, together with Geoff Burks, an astronomer/educator, and

Marino Alvarez, a university educator, participated in this study. These students and their teacher are part of a consortium of middle and secondary schools affiliated with the Tennessee State University's Explorers of the Universe Project, at the Center of Excellence in Information Systems. In this action research scientific/literacy project teachers, students, scientists, university educators, and community persons are involved in collaborative research studies using self-directed cases, metacogntive tools, and interactive electronic learning environments (Alvarez, 1995, 1996,1997, 1998a; Alvarez, Stockman, Rodriguez, Davidson, & Swartz, 1999; Alvarez, et al., 1998; Alvarez & Rodriguez, 1995; Stockman, Alvarez, & Albert, Jr., 1998). Students and teachers research cases of self-interest that present multiple possibilities for resolutions and incorporation into subject disciplines.

Several students took part in the summer program offered through the Explorers of the Universe interdisciplinary scientific/literacy project (http://explorers.tsuniv.edu). The program involves students conducting self-directed case-based research with topics that they felt were interesting to investigate. The two-month session was held during June and July 1999.

Terry King has several students in his class doing case projects in astronomy. He and his students have been working with Marino on the Explorers of the Universe Scientific/Literacy project for four years. For this summer program, Bobby and Addie were interested in doing case research with Black Holes, and Terry served as the teacher of record.

Bobby and Addie were taught how to construct and use vee diagrams and concept mappings by the university educator. The procedures followed those advocated by

Novak and Gowin (1984), and used scoring protocols developed by Alvarez (1998c). The Vee heuristic was developed by Gowin (1981) to enable students to understand the structure of knowledge (e.g., relational networks, hierarchies, and combinations) and to understand the process of knowledge construction. Hierarchical concept maps and Vee diagrams are two methods that students can initiate on their own for schema construction and application. Hierarchical concept maps (Novak & Gowin, 1984) are designed to help the reader clarify ambiguities of a text while simultaneously revealing any misconceptions that result from a reading. More importantly they provide the learner with a tool from which to initiate ideas that can be shared by visual inspection with someone else. The Vee diagram (Gowin, 1981/1987) is a method by which a learner can learn about the structure of knowledge and knowledge making within a given discipline and use this knowledge in novel contexts.

Information is entered electronically by students and collected for analyses in a database at our TSU web server via the Explorers of the Universe web site (http://explorers.tsuniv.edu). Within this site is a linkage to Gateway, a password protected site, that provides entry into a Student Console, Teacher Console, and Researcher Console. Teachers manage their student electronic accounts by assigning passwords, determining the degree of portfolio sharing among students, and responding to student inquires. Students post their thoughts, progress, inquires, and data on their individualized electronic notebook. Likewise, they plan, carry out, and finalize their case-based research using electronic transmissions via e-mail and the Internet of their concept maps and interactive vee diagrams. Students follow sequential stages of the Action Research Strategy: (1) problem/situation, (2) plan/strategy, (3) course of action,

(4) resolution, and (6) action. Each stage corresponds to the epistemic elements arrayed on the Vee Diagram. Their concept maps, vee diagrams, and other pertinent items (e.g., video clips, models, simulations, journal articles, etc.) related to their case report are stored in individual electronic portfolios. Student peer-edited papers are posted on the WWW for others to read and react. Students present their research reports with their teachers, scientists, and university educators at international, national, and state science, mathematics, technology, and literacy conferences. The final process involves students developing CDs of their case research report, which serves as a longitudinal case for others to pursue.

For this study, two students used a newly designed *Interactive Vee Diagram* electronically on the Internet (Alvarez, 1998b). This vee is menu driven and asks students for their name, school address, and e-mail address. Also included are instructions for entering information on the vee. A *Web Site Manual CD* (Alvarez, 1998) was developed as part of the Explorers of the Universe and given to the students and teacher that contains visual, animations, and audio descriptions of vee and concept mapping procedures, and an Action Research Strategy with learner-centered questions in each stage. The teacher acted as a facilitator in this study and became the researcher of his students by testing the effectiveness of the metacognitive strategies and monitoring the progress of their cases by reviewing and responding to their timed writings, journal entries, and written case report. The researchers scored their concept maps and vee diagrams and along with their teacher monitored their daily progress with their case investigation of Black Holes. The astronomer/educator and the university educator received incoming information from the vee and concept mappings of the students and

responded accordingly to their representations and questions. Because these students were at the Center of Excellence doing their case research, both the astronomer/educator and university educator were available for any questions or clarifications that needed to be addressed. However, the use of the Interactive Electronic Network was used by Bobby and Addie as a record for them and us, and provided a venue outside the time they were at the Center for further study and reflection. Bobby and Addie sent notebook entries to Marino, who reviewed and responded to their queries: questions, assurances, records for themselves. Often these entries were written by Bobby and Addie in consultation with each other.

Notebook Entries

Addie expresses the feelings that she shares with Bobby understanding the Vee diagram:

We are unsure as to what our project's world view or philosophy would be.

Bobby follows with a notebook entry that echoes the feeling of Addie's message:

Today, Addie and I have been working on our Vee diagram. We are still a little confused about what we are supposed to type in all of the little blanks, but I think, eventually, we will get it.

Addie and Bobby: I have reviewed your latest Vee. Now you are ready to engage in your research to answer the questions you asked. Once information is collected, put the data in some form: table, chart, graph, etc. This method of presenting your data goes under Transformations. The list answers to your Research Questions. For example, RQ1. Write your finding. RQ2 write your finding, and so forth. Formulate your Principles. State the Value Claims of your final product. Follow the stages in the Action Research Strategy. Send your Concept Map using Inspiration 5.0 via the web site.

After thinking and working on their Vee diagram, Bobby writes:

Addie and I worked on our Vee diagram. We think that we are doing this correctly. We are still not sure what to put for constructs and principles.

Together we discussed the function and purpose of constructs and principles as they related to the Vee and negotiated the entries.

An example of the type of listing as records were some of the resources used by Bobby and Addie recorded in their notebook:

Black Holes and Time Warps: Einstein's Outrageous Legacy by Kip S. Thorne Prisons of Light by Kitty Ferguson Black Holes: A Travelers Guie by Clifford A Pickover A Brief History of Time: From the Big Bang to Black Holes by Stephen Hawking Black Holes in Space by Patrick Moore Black Holes, Quasars, and the Universe by Harry Shipman The Collapsing Universe by Isaac Asimov.

Both Bobby and Addie used Athena, a library search engine, on the Internet. Bobby writes:

We ordered books using the Athena program and they should come in a week or so.

Addie records an entry where she describes how they have programmed the calculator to compute mathematical equations. She makes reference to Mr. King's advanced calculator to program these equations:

Bobby has programmed his calculator to find the mass of a black hole, the circumference of an event horizon, and the Scharzchild radius of a black hole. We have discussed putting the programs onto one of Mr. King's more advanced calculators in order to display them on an overhead.

One of the more interesting entries is their initial reference to a literature piece that they are going to write. Addie writes:

We have decided to include a hypothetical story in our research paper. An astronaut being sucked into a black hole. We will also record the point of view of a near-by observer.

This story was a creative use of incorporating what they were studying; combining factual elements into an interesting humorous series of events. The story was imaginative and intriguing, and complimented the research paper they had written of their case investigation of black holes.

Mediating the Learning Process

The notebook entries and responses serve as samples of the mediation that took place between the university educator and the two students. Meaning was negotiated that led to rethinking of vee diagram entries and search for resources.

Geoff Burks met with Bobby and Addie and served as a resource by facilitating their progress in their case research by guiding them to relevant sources. Instead of giving them answers, Bobby and Addie were asked to reflect on their questions and their writings. This engagement served two functions: 1) further mediated the learning process and, 2) negotiated the curriculum of study.

Evaluation

This study was monitored and evaluated by using Gowin's (1981) four commonplaces of educating: teaching, learning, curriculum, and governance. We also used triangulation (informants, records, and observations) as a method to cross-check our findings (see Denzin, 1978). Gowin's theory of educating is a conceptual approach to

problem solving that focuses on teacher/student social interactions and the ways in which students and the teacher negotiate meaning between and among themselves.

Our assessment of this study indicated that ***teaching*** is achieving shared meaning between the teacher and students, and among students themselves. This was accomplished through shared meanings that resulted from negotiating facts and ideas. Bobby and Addie were at first overwhelmed with the responsibility of forming their own research questions and path of inquiry. This format was different from the one's they had encountered during their formal schooling. Their teacher, the astronomer/educator, and university educator facilitated and mediated their thoughts and feelings as they strived to take charge of their own learning.

Learning in the traditional sense is under the control of the teacher. In essence, the teacher tells students what they need to know. Our philosophy is consistent. We want learning to be placed in a context under the control of the students. In past studies (e.g., Alvarez & Rodriguez, 1995; Alvarez, Stockman, Rodriguez, Davidson, & Swartz, 1999) we have found that students take responsibility when confronted with meaningful projects and materials. We wanted to discern if given the opportunity, would these two students take charge and be responsible for their own learning during a summer session? This question was answered in the affirmative when we read the concept maps, vee diagrams, and electronic journal entries that these students had written in their self-directed case based research. The concept maps showed how reconceptualization of ideas influenced their views on their target concept. The case provided a forum by which the students could take an active role in structuring and creating their own meaning. These two students learned how to use interactive hierarchical concept maps to organize their thoughts, and vee

diagrams to plan and carry-out their investigation. Geoff describes his thoughts about Bobby and Addie during their case research with Black Holes:

I saw a change in the understanding of the students when we dealt with their request for help in finding more material. I make three observations here: 1. The students were not working at the main branch of our school so book resources were limited. The students felt better as they gained experience with web searches. 2. The students seemed to want to build a detailed overview of the entire subject. But in the case of black holes, there is a limit to what can truly be understood without an advanced physics and mathematics background. They seem to have been frustrated that they could not understand everything in the sources. 3. I had to work with the students to limit their search. It appeared that the students were used to the model where they are given a book, and told to learn the material in it. When they have done so, they have mastered the subject. When the students went out to find material, the obtained books containing more and more topics. But the material was not at a level commensurate with their backgrounds, so they felt the need to find more and more material. This led them to more topics, which were difficult to understand.

At this juncture, it was important to fulfill my role as a content person. When we talked I realized that it was important to try to help them limit the scope of their investigation. From experience, I realized that to investigate all the topics we discussed would lead to the creation of a monograph of impressive size. I also knew that some of the topics could not be well understood without previous work with calculus and general relativity. So it became my job to help the students pare down their list of topics to a few questions that were appropriate to their educational background and could be addressed

in a research paper as opposed to a book. When we focused on three questions of interest to the students, they were able to obtain the information they needed through focused search.

A third change that I saw was in the students' reaction to the metacognitive learning tools. The students like the hierarchical concept maps. Students pick these up quickly, in part, because there are only a few concepts involved. The Vee diagram is something different. It is a very powerful tool for planning and carrying out a research project. But the power comes at the price of a noticeably greater level of complexity. In a Vee diagram there are approximately ten new concepts to try to understand and use. The definitions of the terms were given, but they were rather new to me. So, I was not as helpful to the students as I would like to have been. Gowin, who developed the Vee diagram, has an impressive philosophical background. The Vee uses terms derived form philosophy. The students are sometimes confused when their initial personal meanings of the terms differ from the philosophical standard. The students worked hard to fill in the elements on the diagram. Only later was the power of the tool understood. In the future, I will explain and stress the philosophical underpinnings of Gowin's Vee, along with the mechanics involved in completing and using it.

The ***curriculum*** that evolved from this study of Black Holes was emergent rather than fixed. The basic materials went beyond the traditional use of teacher-centered lectures and hand-out materials devised and published by others. Instead, students were presented with a problem/situation and were asked to formulate questions of interest to pursue. Students were also presented with an animated CD that described the uses and functions of concept maps, interactive vee diagrams, and an Action Research Strategy that enabled them

to think about their research. The school climate differed in that these students did not have other classes during this summer period; had the advantage of being at the Center and consulting with the astronomer/educator and university educator as the need arose; and, were able to work together over a sustained period of time during the day unlike a typical classroom time period. Although we do not expect the same kind of learning environment in the summer that occurs in a formal classroom setting during the school, the findings were consistent with our studies that occurred during the school-year (e.g., Alvarez & Rodriguez, 1995, Alvarez, et al., 1999). The events in these sources provide the learner with a record of events as they exist in the past and the present, and serve as a venue for students to make new events happen in the future. These sources guide students to other resources and materials in their quest to seek resolutions to their self-directed cases.

The ***governance*** exercised in this type of study differs from policies and formats that are typical in curriculum guides, teacher's manuals, or module-based lessons. These students expressed their thoughts and feelings freely and made critical decisions. The learning atmosphere was nonthreatening and promoted a social context where ideas were openly shared and discussed. The teacher, in conjunction with scientists, and university educators, guided the students by specifying criteria for executing and completing their cases. However, Bobby and Addie were encouraged to make decisions in governing and conducting their research. This research experience differed from their previous encounters in formal school settings. Geoff remarks:

When we put a student used to the directed methodology into a student centered learning environment, there is a disconnect between previous experience and present reality. This disconnect led to feelings of uncertainty and anxiety because the students

were not familiar with the rules. I had to work with Bobby and Addie to build confidence in their ability to make decisions, and their ability to make choices about their own interests.

Once Bobby and Addie understood that they were part of the decision-making process, they exercised their own form of governance that differed from their past school experiences. More time was devoted to carrying out their case research investigation. The research questions that they asked differ from those that are imposed by a teacher or by outsiders who develop questions with packaged answers. Since they were in charge of their case, they were responsible for analyzing data, making decisions about their worth, using statistical methods, sorting through relevant and irrelevant data sources, and accessing the Internet and to determine whether or not the information was pertinent and authentic. By incorporating other subject-areas into the teaching of his course, Bobby and Addie became aware of how these disciplines are interrelated. Traditional compartmentalized curricula are replaced by one that is interdisciplinary (see Alvarez, 1993).

Concept Maps

The university educator, astronomer educator, a graduate student researcher, and Goli Sotoohi (a TSU researcher with the Explorers of the Universe Project) used a scoring protocol developed by Alvarez (1998c) to independently score the concept maps (see scoring system in Appendix B). Geoff reviewed the concept maps for accuracy, misconceptions, and/or faulty linkages associated with the target concept "Black Holes" and provided feedback to the students via the Electronic Interactive Network. Inspiration 5.0 was used to construct the concept maps and for displaying feedback. Bobby and Addie's first, second, and third concept maps were scored after each was received

electronically. Four raters had identical scores for each map. The total score of the first concept map was 146, after subtracting minus 22 non-valid entries. The second map totaled 87, with non-valid entries accounting for minus 3, and the third map totaled 94 with zero non-valid entries. The first concept map constructed was entitled "The Life of a High Mass Star," and contained many concepts most of which consisted of misconceptions that students believed to be accurate (see Figure 1).

[Insert Figure 1 about here]

Geoff met with Bobby and Addie and suggested that specificity of the topic for investigation would yield more information, rather than a conglomerate of concepts that would cause more problems than it solved. It was agreed that Bobby and Addie would focus on "Black Holes" for their case investigation.

In reviewing the second revised map there were marked differences from the first (see Figure 2).

[Insert Figure 2 about here]

"Black Holes" became the superordinate concept with "Clues to their existence," Reactions with matter," and Reactions with us," occupying Level I of their map. These three subordinate concepts were, in essence, Research Questions 1, 2, and 3 in their Vee Diagram. Under "Clues to their existence," comprising Level 2, were subcategories "gravitational lensing," redshifting," "X-rays," "gravitational forces," with a subcategory "binaries" comprising Level 3. "Reactions with matter," showed subcategories of "time," and "spaghettification." The third, "Reactions with us," showed an example of an "astronaut. This needed clarification.

Geoff wrote comments on their second map suggesting three areas to consider. These suggestions were sent electronically and appeared on Bobby and Addie's second map.

[Insert Figure 3 about here]

First, he suggested under "Reactions with matter" that the word phrase linking the subordinate concepts, "time' and "spaghettification" be changed to read "include" for both propositions instead of "and." Second, a question was posed to Bobby and Addie concerning the inclusion of "Binaries" listed under "Gravitational Forces." The response asked them to consider whether or not they wanted to include "Binaries" in their study of black holes. Finally, under "Reactions with us", the linking words "for example" were nebulous because this connection did not relate "astronaut" in a meaningful way. Therefore, a question was raised concerning this relationship and how it could better be explained. Bobby and Addie met with Geoff concerning his comments on this map. Upon reflection, Bobby and Addie decided to delete "Binaries" in order to concentrate on other properties of black holes that related to their research questions.

The revised third, and final map, contained the same information as the second with the exception of deleting "binaries" and clarifying the linking from "Reactions with us" by writing a word phrase on the linking line "what happens to an" 'astronaut' and then further clarifying this notion by writing a linking phrase "goes into a" to the concept "Black Holes" (see Figure 4).

[Insert Figure 4 about here]

In this third concept map, the "binaries" entry is not listed indicating a shift in the emphasis of the inquiry. It may also indicate a broadening of understanding with the general topic, since the study of binaries is not the only place where the study of gravitational forces implies the existence of black holes. The study of gravitational forces in the center of galaxies, also implies the existence of black holes.

Comparing the three maps, one can visually discern how the students formulated and organized their thoughts in the first concept map, and how they actually researched the topic and methodically organized their thoughts in the second concept map. Their third map incorporates the ideas from the second map and refines their thought processes resulting in a more focused approach to their case investigation. Their maps reveal their thought processes as they progress from each respective map. When reviewing the scoring protocol for the Vee, it was important to note the column labeled Not Valid. We feel that a teacher using this scoring protocol that the Not Valid column serves as a check for misconceptions or faulty linkages and alerts the teacher to mediate conceptual learning with the student.

The maps also aided Bobby and Addie to self-monitor their progress and achieve a better understanding of their case by clarifying conceptual relationships as evidenced by the rethinking of their ideas revealed in the second and third revised map. The astronomer/educator and university educator became better informed regarding student learning contexts as they studied their research.

The teacher, astronomer/educator, and university educator gave feedback to the Bobby and Addie. Both Bobby and Addie indicated that the Vee helped students to better understand connections between the conceptual and methodological sides of the

Vee, which, in turn, helped them to understand in a meaningful context the value of the knowledge claims of their case research on Black Holes.

Time Writing

Time writings (see Alvarez, 1983b, 1993) were used to assess students' prior knowledge, world experience, and degree of spontaneous relationships and understanding of the specific topic of study in the self-directed case on Black Holes. These time writings occurred after the completion of their final concept map. Qualitative evaluations were analyzed by coding the data and then using NU*DIST 4 software to organize the data sets.

Bobby and Addie were each asked to write about their case "Black Holes." They wrote for six minutes without stopping their pens in the process. They were told beforehand that if they couldn't think of anything to write they were to write their first and last names over and over until another thought came to mind. Geoff reviewed both Bobby and Addie's timed writings and checked them for accuracy, misconceptions, or faulty reasoning. He then provided feedback to these two students after they were analyzed.

Marino, Geoff, and Goli Sotoohi each read the two timed writings and selected words and word phrases for purposes of coding and comparison. Word and word phrases were selected according to relevant specialized vocabulary associated with the key target concept "Black Holes." Agreements were decided on the word and word phrases selected based on Geoff's expertise with this topic. A total of sixteen words were chosen for coding and comparison. Marino then typed each writing and entered them into the NU*DIST 4 search program. A word search revealed the number of times that a specific

word or word phrase was written or repeated in a given writing. The time writing by the two students, Addie and Bobby, had many items in common. The key words and word phrases were used almost evenly though each student's writing.

Bobby seems to use words that reflect the observational approach. For example, Bobby writes, "there are multiple ways to detect black holes including gravitational lensing, gravitational redshifting, X-ray radiation, and gravitational forces." Bobby goes on to explain each of these terms and their characteristics in his writing.

Addie's approach to spontaneously writing about the existence of black holes is similar to Bobby's in that she lists and describes most of the same terms, however, she begins her writing with a theoretical orientation. For example, she opens by writing "Black holes are theoretical regions of space that have a singularity and an event horizon." She then describes clues to the existence of black holes that is within the realm of an observational approach similar to Bobby's writing.

The key words used by both students are *redhifting*, *radiation*, *observation*, *mass*, *light*, *X-ray*, *gravitational lensing*, and *gravitational forces*. It seemed that both students focused on "redshifting" and "light."

Bobby uses the following key words, which are not used by Addie:

Spectrum

Gravity

Gamma rays

Curvature

Addie used the following words not used by Bobby:

Speed of light

Event horizon

Density

Singularity

Upon completion of this qualitative analysis, we then compared their time writing to their concept map displays: their first and last map.

Their first concept map was general and focused on both the creation of black holes and its properties (see Figure 1 above). After meeting with Geoff, Bobby and Addie redirected their thinking to focus more on the properties and characteristics of black holes as revealed in their second and revised final concept map (see Figures 2 and 3 above). The revised final map slightly differed from the second in that the second map included "binaries" under "Gravitational Forces" and was deleted from the final version. Also, under "Reactions With Us" "astronaut" was listed as an example (refer to section on concept maps above).

Comparisons of each time writing to these two maps revealed that Addie retained more of the ideas depicted in the first map than Bobby who relied on the second, and revised final map for his reference. Addie incorporated word and word phrases that were depicted on the first map. For example, the concepts "event horizon," and "singularity" that were noted on the first map, but not on the second or revised final map, were included. However, Bobby omitted these two concepts in his writing. Addie's reference to the first map is also mentioned in her writing when she states, "Black holes are formed when a star collapses in on itself." This is an implied statement referencing the "Life of a

High Mass Star" shown on the first map. Bobby's writing incorporated concepts displayed on the final map more so than the first. For example, the theme of Bobby's writing is predicated on observational "Clues to the Existence" of black holes shown on this map.

Despite revised forms of these maps, Addie seems to hold onto original thoughts about how the topic of Black Holes should be approached, while Bobby moves along a continuum toward a more focused approach to this topic. This seems to concur with Addie's theoretical approach in her writing compared to Bobby's concrete observational stance.

Time writings were valuable for all parties involved in this collaborative research project. These spontaneous writings provided the teacher with knowledge that students possessed as they progressed with their inquiry. The university and science educators were able to evaluate student progress and conceptual understanding with the target concept. These writings provided a basis for the teacher, university, and science educator to provide feedback to the students, and to compare these entries with the ideas portrayed on their concept maps. Students were able to reflect on these comments, reconceptualize, and self-monitor their learning.

Interactive Vee Diagrams

Bobby and Addie used the Vee Diagram to plan each phase of their case research. At first the students had difficulty understanding the epistemic elements (function and purpose) arrayed on the Vee. After Marino met with Bobby and Addie, a better grasp of how these epistemic elements operate interactively between the conceptual and methodological sides of the vee were understood (see Figure 5).

[Insert Figure 5 about here]

Scoring procedures of student Interactive Vee Diagrams followed a modified protocol suggested by Novak and Gowin (1984, pp.70-72) and developed by Alvarez (1998d). Vee diagrams were scored on a quality point scale (0-4) with a maximum score being 30 in two stages using the following criteria (point values in parentheses for each of the categories): research question(s) (0-3), objects/events (0-3), concepts (0-4), records (0-3), theory (0-2), world view (1), philosophy (1), principles (0-4), transformations (0-4), knowledge claims (0-4), and value claims (0-1). Stage 1: Research Question(s), Events/Objects, Concepts, Records, Theory, World View, Philosophy, Principles, and Transformations (preliminary plans to analyze and represent the data). Stage 2: All components of the Vee were evaluated.

The university educator, and the astronomer/educator, evaluated the Vees by Bobby and Addie. Three Vee Diagrams were evaluated. The first Vee "Black Holes" Stage 1 scores by the two respective raters are given in parentheses: Research Question(s) (2,2), Events/Objects (1,1), Concepts (0,0), Records (2,2), Theory (0,0), World View (0,0), Philosophy (0,0), Principles 0,0), and Transformations (2,2). Total equaled (7,7).

This first vee contained four research questions: RQ1 How are black holes formed? RQ2 What are the properties of black holes? RQ3 Where is Vulcan? RQ4 What would happen if you fell into a black hole? Bobby and Addie were asked to reconsider their research questions in light of an absence of a theory, world view, philosophy, and concepts. These were required components for Stage 1 of the vee diagramming process. They cited books and the Internet as sources under records. Records are "facts" that can

be gathered based on the events. An explanation was given to Bobby and Addie for selecting instruments to record their findings.

After feedback by the astronomer/educator the second Vee, "Black Holes IV: The Voyage to What Used to be Home," was scored: Research Question(s) (3,3), Events/Objects (2,1), Concepts (2,3), Records (3,2), Theory (2,2), World View (1,1), Philosophy (1,1), Principles (0,0), and Transformations (2,2). Total equaled (14,13). In this second vee, three research questions were posed: RQ1 How do we know that black holes exist? RQ2 How does matter interact with them? RQ3 How would we interact with them? These three research questions corresponded with their three primary classifications displayed on their second and third concept maps. A theory was stated, "The gravitational forces of black holes are so strong that not even light can escape." Concepts were given that were necessary in understanding and carrying out the research: "black holes," "event horizons," "gravitational forces," "redshifting," and "singularities." Their world view stated, "Black holes are giant vacuum cleaners in space. Black holes exist in our driers and feed on our socks." In their philosophy they stated, "Black holes are still theoretical but there are many clues pointing to their existence." Under records were listed "written notes," the electronic notebook," diagrams," and "our brains."

Feedback was given via the Electronic Interactive Network, whereby students slid their mouse over the icons that contained "pop up" responses to their second Vee Diagram. For example, in the area of Events/Object a suggestion was to strengthen the method for answering the Research Questions, also "diagrams" were suggested as a way to transform the data and be placed under Transformations.

The final revised Vee, “The Final Spaghettification,” was scored: Research Question(s) (3,3), Events/Objects (2,1), Concepts (2,3), Records (3,2), Theory (2,2), World View (1,1), Philosophy (1,1), Principles (0,0), Transformations (4,4), Knowledge Claims (3,3), and Value Claims (1,1). Total equaled (14,13). Again research question 1 took a slight transformation: RQ1 What are the clues to the existence of black holes? RQ2 How does matter interact with them? RQ3 How would we interact with them?

Transformations contained their concept maps, and a calculator program. Their knowledge claims were in answer to their research questions. They determined that “There are many clues to their existence including x ray radiation, gravitational lensing, and gravitational forces. Any matter going into a black hole would be vertically elongated and horizontally compressed.” It was not clear under Knowledge Claims if the RQ3 had been answered. The astronomer/educator felt that RQ3 may have been answered by extension of RQ2 if one is to understand the “we” refers to humans are included in under “matter.” However, this connection was not explicit. The university educator also felt that RQ3 was not addressed. However, there was a story that Bobby and Addie had written to describe the events of a fictional character and his encounter with a Black Hole that served to answer this question in a unique manner by describing the process of a human (matter) entering a black hole. Both raters were able to reach conclusions with RQ3 based on their interactions with Bobby and Addie during the course of their case investigation. The value claims resulting from their study stated, “This research helps to clear up the myths and fears of black holes by learning the real evidence.” The vees enabled collaborative efforts between the students, university

educator, and astronomer/educator, and aided in clarifying meaning and negotiating uncertainties during the research investigation.

Comparing Concept Maps, Vee Diagrams, and Time Writings

An analysis of Bobby and Addie's concept maps, vee diagrams, and time writings reveal that they first approached their topic from a theoretical stance. This position led to the asking of broader questions on their first vee, RQ1 How are black holes formed?, and is shown on their first concept map "The Life of a High Mass Star." Their initial approach was to investigate black holes from a more general perspective. They focused on the origins and characteristics of black holes. Both Bobby and Addie express this view in their time writings. Addie's time writing devotes a half page addressing the theoretical aspect of this topic. For example, she writes, "Black holes are theoretical regions of space that have a singularity and an event horizon." Bobby also writes "Black holes are a theoretical possibility of what happens at the end of a life of a high mass star." This statement is a verbal description of a graphic representation in their first concept map.

As a result of Geoff's feedback, they decided to redirect their efforts to the characteristics of black holes as evidenced in their second and third vee diagrams. Analysis of these subsequent concept maps and vee diagrams indicate a more critical examination of the existence of black holes. This shift in thinking from *origins* to *evidence* is apparent in their second and third vee diagrams in their research questions, world view, philosophy, and theory. Bobby, in his time writing states, "Black holes are regions of space that the pull of gravity is so strong that nothing not even light can escape." This statement is exactly stated in the "Theory" of their second and third vees.

Survey

Evaluation of Bobby and Addie's responses to the Survey we gave on the last day of their participation indicated their thoughts and feelings of what they had accomplished (see Appendix C). Their responses were electronically submitted jointly and, upon further inquiry, concurred with one another.

The ability to self-select a topic of interest for research was valued by Bobby and Addie. They stated that they had difficulty at first with the elements arrayed on the Vee Diagram. Compared to other school projects this one was more "challenging" and the need to select a topic for study was more interesting. They both agreed that the Vee Diagram was "hard to figure out." The concept maps helped them to "sort out our ideas." The feedback they received on their Vee Diagrams "was more helpful than [written] original instructions." The feedback on their concept maps "helped us to put our ideas in the right places." Formulating their own research questions "was different and more challenging than school work, but it was also more interesting." They thought that timed writings were "nerve wracking." Both thought that using concept maps and vee diagrams changed their way of thinking. "Once we figured out [understood] it [vee] it gave us an interesting perspective on the project. The concept map was instrumental in our projects' organization. While the vee diagram seemed to interfere at first, both tools had their good qualities in the end." When asked their candid appraisal of the use of techniques and procedures during the project and the degree of learning that transpired compared to other learning experiences encountered previously, they felt that they had learned "more than" other school-related experiences. "This format of learning allowed

me [us] to focus on one subject for a longer period of time than other courses would. I [we] liked being able to give full attention to one project."

The responses indicated changes in both attitude and accomplishment experienced by Bobby and Addie. Four primary findings from this survey suggest that mediation between these students and teacher/researchers were:

1. Aided the student to adjust to student-centered learning;
2. Aided the student in focusing on research questions that not only interested them, but also could be successfully addressed with previous background;
3. Aided the students to successfully learn and use the metacognitive learning tools in their research project; and,
4. Provided an opportunity to engage in a self-selected research over an extended period of time.

Discussion

Understanding thinking-learning contexts leads to a conceptual change approach to teaching and learning. This kind of approach should include explicit ways for teachers, students, and affiliated persons to become aware of their own beliefs and to come to understand the nature and construction of knowledge. Interactive Vee Diagrams, concept maps, and electronic notebooks that are shared on the Internet provide collaborations that inform practice and, in the process, provide an electronic forum for facts and ideas to be learned and communicated meaningfully.

This action research study suggests that informed practice is beneficial for teachers, researchers, and students. Students became aware of their own thought processes and developed a more positive approach to initiating research questions as they

planned, carried out, and finalized their case based research. Likewise, teachers/researchers became more knowledgeable about their own practice as well as learning about the ways in which students engaged in thinking/learning contexts as they progressed with a case couched in a problem-oriented context. This knowledge is important not only for teaching and learning but also provides an alternate forum for policy-makers to be aware of what students can do once they are given time and allowed to pursue their own paths of inquiry without restraints of a restricted curriculum. Rather than following a "fixed" curriculum, Bobby and Addie were able to pursue one that was "emergent" based on concentrated inquiry of a self-selected topic that provided for reflection, modification, and time for thinking about these ideas and their relationships.

Cognitive dissonance is an important consideration when formulating research questions pertinent to a given action research problem or situation. Initially there are conflicting theories that cause consternation in the development of focused research questions. Cognitive dissonance is "an antecedent condition which leads to activity oriented toward dissonance reduction (Festinger, 1957, p. 3). To reduce this conflict, strategies need to be initiated that focus on the resolution of a stated problem or situation. In this study, concept maps and vee diagrams aided in the reduction of conflicting viewpoints by aiding Bobby and Addie to organize and plan their research questions, follow a methodology, and test a theory with their target concept "Black Holes."

It is this reconciliation process that occurs throughout the action research phases that account for reconceptionalizaton of ideas and a better understanding of one's thinking/learning contexts with a given problem or situation. In this case, both Bobby and Addie were confronted with a problem/situation that required them to think about

possible resolutions. Their thought processes took them beyond requirements commonly needed for accomplishing conventional school requirements. Teachers/researchers became facilitators during the processes of identifying an idea or problem area; (2) studying the problem by formulating research questions and making judgements of the epistemic elements arrayed around the vee diagram; (3) gathering data; and (4) reflecting on the data in order to answer their research questions and determine the value of their inquiry. The teachers/researchers in this investigation engaged in similar reconceptulations and reconciliations in reviewing and responding to notebook entries, concept maps, and vee diagrams.

Thinking/learning contexts were better understood as a result of this investigation. Informing practice through collaborative partnerships lead to a conceptual change approach to teaching and learning and served to alter our mental models of both the topic and processes of learning and understanding. It extended our knowledge for an alternative to conventional approaches that should include explicit ways for teachers and students to become aware of their own beliefs and to come to understand the nature and construction of knowledge. Interactive Vee Diagrams and concept maps served as metacogntive tools that aided in negotiating this learning process. Timed writings enabled the teacher/researcher to follow the understanding and progress of these students with their case research. These interactive communications and rethinking of ideas resulting from collaborative meaning-making aided students, teacher, scientist, and university educator alike to better understand the learning process and search ways to make learning meaningful.

Throughout this action research investigation Bobby and Addie were encouraged to seek answers to their own questions, sort through electronic and print mediums, make judgements, and synthesize facts and ideas as they progressed in their case research. During this process they reflected on what they knew about the selected topic. Their mental model was altered as they studied "Black Holes" and negotiated the learning process between themselves and the teacher/researcher. Evidence was provided of their learning and understanding with this topic through their visual displays on their concept maps, entries on their vee diagrams, time writing, and notations and questions in their notebook entries. Further, they wrote a story that incorporated the facts and ideas of their research with a fictional account about Vincent and his journey into space in the year 2334 to explain the effects that black holes would have on matter such as humans. This imaginative story illustrates the importance of not only understanding scientific facts and ideas, but the ability of these two students to infuse them into a creative portrayal that provides the reader with a better understanding of their research topic "black holes."

In this investigation Bobby and Addie became active participants in action research. They self-monitored and assessed their own learning as they engaged in the phases of the Action Research Strategy to guide their inquiry. During the process both Bobby and Addie took charge of their actions through deliberate learning: accepting responsibility, pursuing paths of inquiry, weighing facts and ideas under plausible and meaningful circumstances, and by providing evidence of personal meaning and ownership through research.

Acknowledgements

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Figure 1. First Concept Map: "The Life of a High Mass Star"

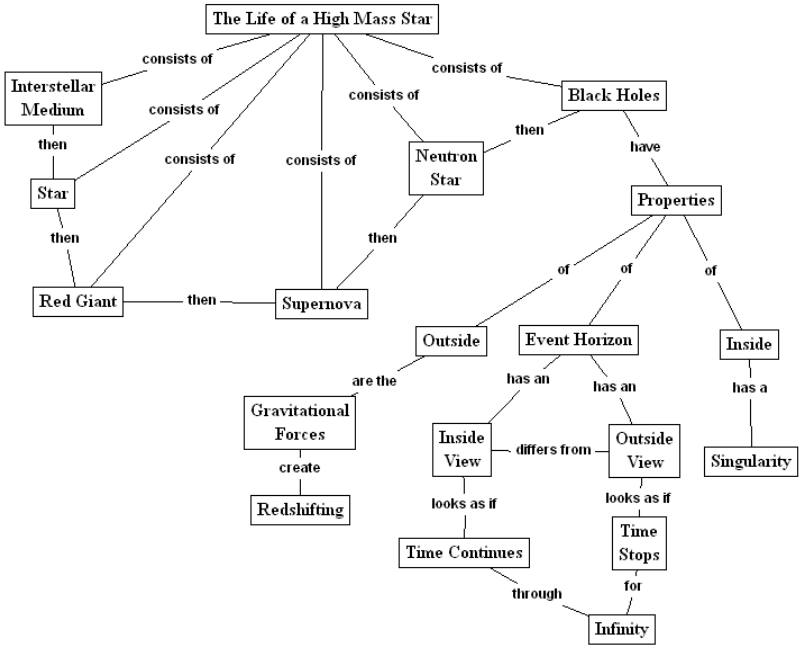


Figure 2. Second Concept Map: “Black Holes”

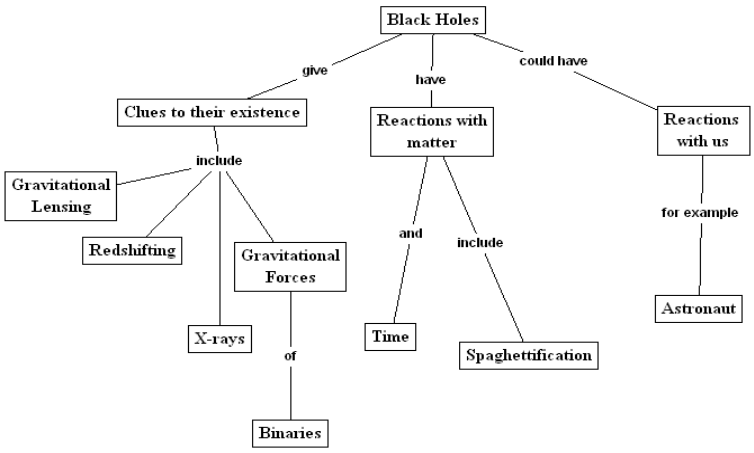


Figure 3. Third Concept Map: "Black Holes – Reviewed"

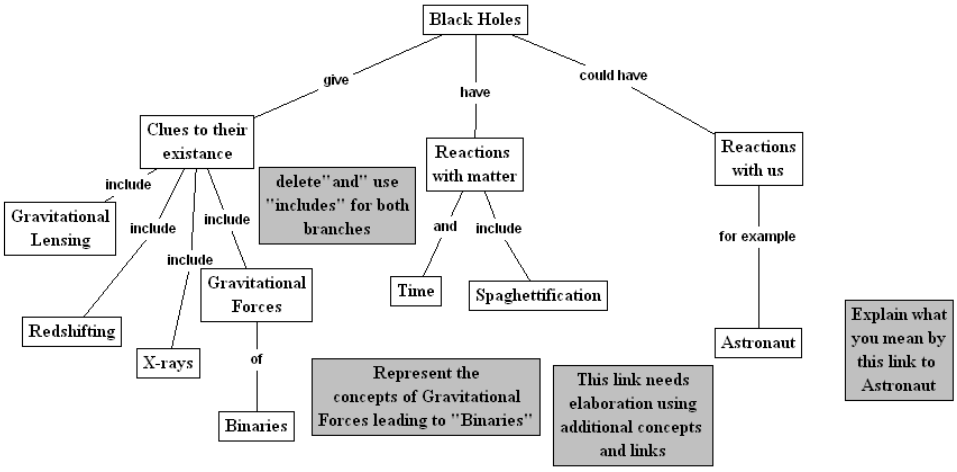


Figure 4. Final Concept Map: “Black Holes”

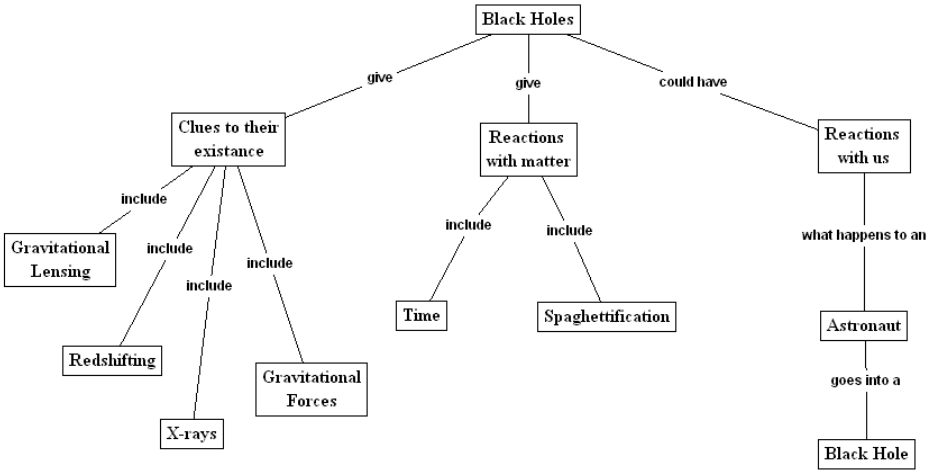
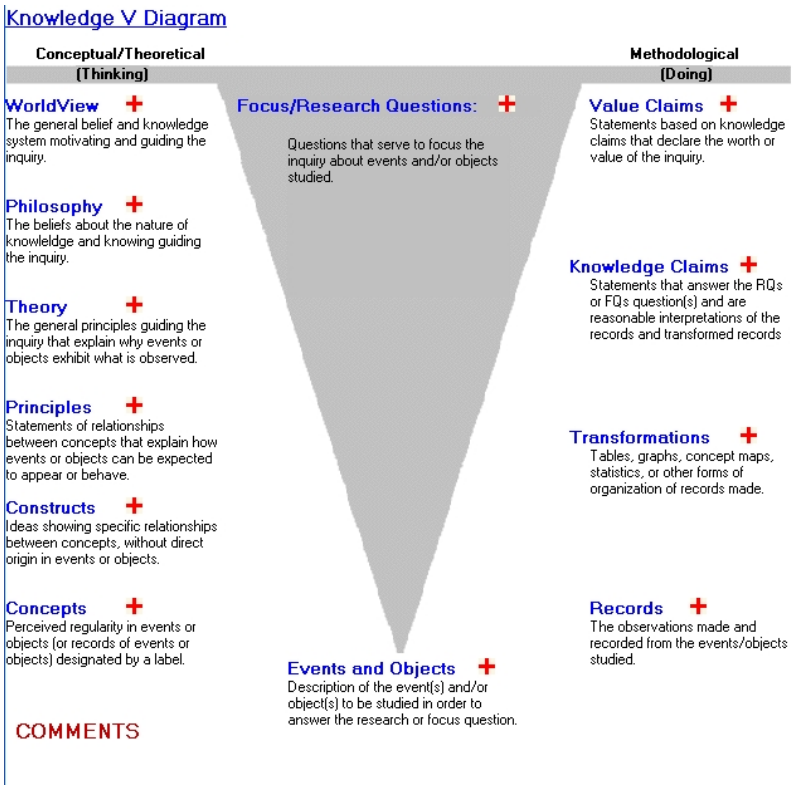
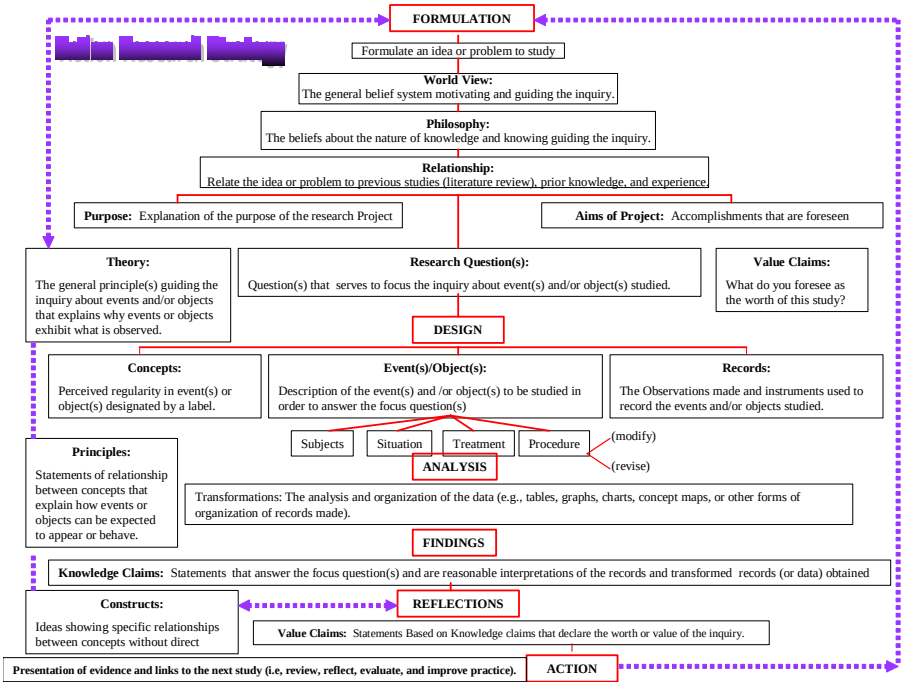


Figure 5. Gowin's V Diagram



Appendix A

Action Research Strategy



Appendix B

Scoring Criteria for Concept Maps*

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Hierarchy. The map shows hierarchy by displaying different levels of space. It moves from most inclusive concept, to less inclusive concepts, to least inclusive concepts: superordinate, coordinate, subordinate. Five (5) points are awarded for each level of space (see Scoring Model). Examples and non-examples do *not* constitute a level.

Relationships. Each concept is linked by a line which signifies a *proposition* (a meaning relationship) between two concepts. In order to receive points the concept should be connected to the other and be meaningful. If the relationship is valid and the word or a word phrase is labeled on the proposition (line) one three (3) points are awarded. If the relationship is valid, but is not labeled one (1) point is awarded. Cross-links, examples and non-examples are *not* counted as relationships.

Branching. This occurs when a coordinate or subordinate concept has links to several specific concepts. *Within* each hierarchical level, points are awarded for each coordinate, subordinate, and specific concept listed within a grouping: Level 1 = 5 points; Level 2 = 4 points; Level 3 = 3 points; Level 4 = 2 points; Level 5 and beyond = 1 point. Examples and non-examples are *not* counted as branches.

Cross Links. Ten (10) points are awarded when one meaningful segment of the map is connected to another segment of the map (shown by a broken line in the Scoring Model). This cross-link connection needs to be both valid and significant. Cross-links indicate thought, creative ability, and unique awareness.

Examples. Specific events or objects that are valid instances of a designated concept are awarded one (1) point *within* the listing regardless of the number. These examples are *listed*, not circled, since they represent *specific items* of the labeled concept. For example, under the subordinate concept "reptiles" a listing appears such as: 1. Snake 2. Lizard 3. Alligator. Even though three examples are *listed*, the total is one (1) point.

Non-Examples. Specific events or objects that are *invalid* instances of a designated concept are ***stated*** *as non-examples*. One (1) point is awarded *within* the listing regardless of the number.

Deductions

Faulty Links. Linkages to concepts that are *invalid* or are *misconceived* are deducted from the total number of points for each category. These faulty linkages are very

important in the learning process. They serve as points to discuss with the learner for clarification and further understanding of the target concept.

***Notes:**

Total points may exceed one hundred (100) depending upon the number of valid and significant entries portrayed on the concept map. A word of caution concerning scoring of hierarchical maps. Scoring is secondary to the purpose of constructing concept maps. The rater uses scoring as an ancillary record. The primary use of scoring is to aid the developer by clarifying conceptual ambiguities, faulty linkages, and extending their knowledge with the target concept. Scoring criteria is not shared with the learner. Instead, the scoring by the rater allows more in-depth review of the map and provides points of discussion with the learner. The difficulty establishing a static scoring system lies with the organic nature of the map itself. The map is a visual representation of an individual's thought processes and therefore, by its nature, evolves into various states. The stage at which the map is scored and analyzed represents a slice of the condition with the target concept as it exists at the time it was developed. The teacher may wish, in some instances, to construct an exemplar concept map and use it as a basis for comparison scoring. However, caution is advised due to students being able to construct a map that may differ from that developed by the teacher, but includes pertinent and relevant information associated with the Key Target Concept.

Scoring Sheet:

In the column labeled "**Total**" calculate the total number for each category using the formulas given. In the column labeled "**Not Valid**" determine how many invalid or misconceptions exist and using the formulas on the left column calculate how much needs to be deducted in each category (use minus sign). In the last column labeled "**Total Valid Score**" simply subtract the total score from the "Not Valid" score for each category in order to calculate the grand total.

Teachers and researchers can use the "Not Valid" and "Total Valid Score" to determine student progress. The "Total Valid Score" may not be as descriptive and instrumental as the "Not Valid" score. The "Not Valid" score can be used as a diagnostic tool or measure to indicate how students learning a specific concept progress over time. For example, if the "Not Valid" score decreases as a student constructs subsequent maps on the same target concept, one may conclude that the student has fewer misconceptions about the topic and has a greater understanding of the target concept.

Appendix C

SURVEY

Please answer the following questions/statements using your Electronic Notebook. The following questions/statements relate to your experiences with your selected project in the Explorers of the Universe Project.

1. What I enjoy most about this research project . . .

2. What I dislike most about doing the research project . . .

3. Compared to other school-related projects that I have been involved with this one . . .

4. The Vee Diagrams . . .

5. The Concept Maps . . .

6. The feedback on the Vee Diagrams . . .

7. The feedback on the Concept Maps . . .

8. Having to formulate my own research questions . . .

9. Timed writings . . .

10. Did using concept maps and vee diagrams change your way of thinking about learning? Is so how? If not, how did they interfere?

11. Using the techniques and procedures that you were asked to complete during this project, what would be your candid appraisal of learning in this format as compared to other courses or learning experiences you have been involved? Less than, About the same, More than. Explain your thoughts and feelings.