Running Head: Technologically-Rich Activity Systems

Using Activity Theory to Understand The Contradictions Characterizing a Technology-Rich Introductory Astronomy Course [1]

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Using Activity Theory to Understand The Contradictions Characterizing a Technology-Rich Introductory Astronomy Course

ABSTRACT

We are once again witnessing a shift in science education from telling students about "ready-made" science to engaging participants in the "making of" science. Consistent with this latter view of science education is our Virtual Reality Solar System course in which students build virtual solar systems and, in the process, rich understandings of astronomical phenomena. In this report of our research, we use the central tenets of Activity Theory to understand and illuminate how our course supports the emergence of activity systems that transform objects through which students, as subjects in these systems, develop deep and meaningful understandings. Specifically, we focus on the relations of subject and object (VR models and astronomy understandings) and how, in our course, object transformations leading to deep scientific understandings are mediated by tools (both technological and human), the overall classroom microculture (emergent norms), division of labor (group dynamics and student/instructor roles), and rules (informal, formal, and technical). Our data pointed to two central contradictions as characterizing the course activity system. With respect to the first contradiction, we examined the tensions between learning astronomy and building VR worlds. Results suggested that instead of detracting from the emergence of an activity system that supported learning astronomy, the building of VR models frequently co-evolved with learning astronomy. Said another way, building models and learning astronomy were the same activity. With respect to the second contradiction, we examined the tension between pre-specified, teacher-directed instruction versus emergent, student-directed learning. Our results indicated that it was neither teacher-imposed nor student-initiated constraints that directed learning; rather, rules, norms, and divisions of labor arose from the requirements of building and sharing VR models.

INTRODUCTION

Currently there is a shift in how cognition and instruction are conceived, with an increasing number of educators abandoning predominantly didactic, lecture-based modes of instruction and moving toward more participatory models in which students, frequently in collaboration with peers, are engaged in problem solving and inquiry (Land & Hannafin, 1996; Roth, 1996). This is consistent with leading science educators who advocate for <u>active learners doing scientific investigations</u>, instead of passive learners receiving science instruction (Ruopp, Gal, Drayton, & Pfister, 1993; Solloway, Krajcik, Blumenfeld, & Marx, 1996). What is needed is a shift from telling students about "ready-made" science to engaging participants in the "making of" science. Although some forms of direct instruction are effective for achieving specific objectives (e.g., direct instruction of reading strategies, see Roshenshine, 1986), the same practices that make these approaches beneficial (e.g., eliminating extraneous information, telling students correct answers, pre-defining knowledge) may be inadvertently causing the knowledge to become inert (Whitehead, 1929). Papert (1991) writes:

> Telling children how scientists do science does not necessarily lead to far-reaching changes in how children do science; indeed, it cannot, as long as the school curriculum is based on verbally expressed formal knowledge. (pp. 10-11)

In this article, we discuss the implications of our research/instruction, in which we have been developing technology-rich, participatory learning environments for engaging learners in constructing accurate understandings about scientific phenomena. We have engineered our research and development as a series of "design experiments" (Brown, 1992), with the intention of carrying out multiple layers of analysis. This process involves introducing various design modules (thought experiments, stand-and-deliver sessions, compare/contrast sessions, modeling challenges) in our courses and "tracing" the emergence, evolution, and diffusion of practices, understandings, perceived constraints, and artifacts as they relate to each module. Findings related to these various levels of analysis are then fed back into our classrooms and we continue to examine how these innovations impact the learning process.

In discussing the implications of this research and to better understand the potential of our work, we will conceptualize this discussion using the theoretical framework of Activity Theory (Engeström, 1987, 1993; Leont’ev, 1974, 1981, 1989; Nardi, 1996). More specifically, in this report of our research, we use the central tenets of Activity Theory to illuminate how our course supports the emergence of activity systems that transform objects and enable students, as subjects in these systems, to develop deep and meaningful understandings. Given that activity systems are characterized by inner contradictions, the central focus of data reporting and analysis will be on two primary contradictions that were of concern throughout course development and implementation: the tension between learning astronomy and building VR models and the tension between pre-specified, teacher-directed instruction versus open-ended, student-directed learning.

BACKGROUND

Acquisition versus Participation Metaphor

Beginning with the cognitive revolution of the Sixties, <u>representation</u> has served as the central concept of cognitive theory with the representational theory of mind being the most common view in cognitive science (Gardner, 1985; Fodor, 1980; Vera & Simon, 1993). The central tenet of this position is that "knowledge is constituted of symbolic mental representations, and cognitive activity consists of the manipulation of the symbols in these representations, that is, of computations" (Shannon, 1993; p. 70). In contrast, others have argued for a shift away from a representational theory of mind toward a theory of activity and enculturation that is predicated on a situative philosophy (see Greeno, 1998).

A move towards activity-based (participatory) theories and away from a representational epistemology is also consistent with the works of Dewey (1925/1981), Rorty (1979), and Quine (1969), who rejected conceptual representations as primary in explaining learning. Such a shift is also consistent with Sfard's (1998) distinction in terms of a movement from an "acquisition" towards a "participation" metaphor for describing learning. While the former stresses the individual mind and what goes into it, the latter emphasizes learners' activities and, specifically, their participation in a trajectory of participation, suggesting "that the learner should be viewed as a person interested in participation in certain kinds of activities rather than in accumulating private possessions" (Sfard, 1998, p. 6). The focus on participation represents a conceptual shift, from conceiving of learning as "'receiving' a body of factual knowledge about the world; [to conceiving of learning as an] activity in and with the world" (Lave & Wenger, 1991, p. 53). In a significant way, learning as participation replaces the notion of a codified body of knowledge, instead representing knowledge as embodied in action within a context.

Although this focus on participation clearly emphasizes the practices of the learner, the reader should not conflate this perspective with the positivistic and reductionist behaviorism advocated by Skinner and his followers in which learning is simply stimulus-response connections, resulting in conditioning and socialization. Our conception of practice "includes those that are more conceptual in nature (e.g., recognizing relations among objects, underlying principles, or even attributing meaning to an event), as well as discursive practices that are dependent on language (e.g., communication, argument)" (Barab & Duffy, in press, p. 23). Further, like Rorty’s (1979) epistemological behaviorism and Dewey’s (1925/1981) pragmatic social behaviorism, the perspective being advanced is postpositivist in that it rejects theory/fact and fact/value dualisms, and is non-reductionist in that it conceives practice (activity) as part of a system (Garrison, 1995). It is in clarifying the important features and dynamics of an activity system that we turn to a discussion of Activity Theory.

Technology-Rich Participatory Learning Environments

Moving away from teacher-centered or lecture-based environments, we have been developing participatory learning environments that are technology-rich and allow students to ground their understandings within their own concrete experiences. We refer to these environments as technology-rich, inquiry-based, participatory, learning environments for grounding understanding (TRIPLE-GU) (Barab, Hay, & Barnett, 1999; Barab, Hay, Barnett, & Squire, 1998). These environments take advantage of emerging technologies to establish participatory learning environments that immerse students within contexts that challenge, ground, and, ultimately, extend their understandings (see Table 1 for a list of the central features). The emphasis of participatory learning environments is not the teachers’ fixed curricular objectives but rather the learners’ emergent practices in relation to the need at hand. It is a move from a “teacher curriculum” to a “learner curriculum” (Lave & Wenger, 1991), or from an “acquisition” metaphor to a “participatory” metaphor (Sfard, 1998).

[insert Table 1 about here]

Predicated on a social constructivist philosophy, the role of teacher switches from one of telling students correct answers to guiding student activity, as they direct their own learning process (Bednar, Cunningham, Duffy, & Perry, 1992; Dewey, 1963; Edwards, 1995; Vygotsky, 1978). Consistent with Papert’s (1991) constructionist pedagogical framework, participatory learning environments support learners' building understandings through the collaborative construction of an artifact or shareable product. These environments are frequently collaborative in nature, with students negotiating goals, tasks, practices, and meanings with peers (Blumenfeld, Marx, Soloway, & Krajcik, 1996; Nastasi & Clements, 1991; Savery & Duffy, 1996). Rather than presenting instructional treatments, the goal is to establish rich environments that encourage explanation and discovery, nurture reflection, and support students in carrying out practices that embody personally meaningful and conceptually functional representations (Barab, Hay, & Duffy, 1998; Hannafin, Hall, Land, & Hill, 1994; Jonassen, 1991). Said another way, these environments are intended to support the emergence of activity systems that allow learners to extend their understandings.

In general, technological advancements have made possible many new exciting learning opportunities, supporting students in collaborative learning and inquiry (Barab, Bowdish, & Lawless, 1997; CTGV, 1993; Edwards, 1995; Jonassen, 1996; Koschmann, 1996; Scardamalia & Bereiter, 1994; Winn, 1995). In particular, we have been investigating the potential of virtual reality (VR) to support participatory learning experiences (Dede, Salzman, Loftin, & Sprague, in press; Hay, Johnson, Barab, & Barnett, in press; McClellan, 1996; Olson, 1998; Winn, 1995). Virtual reality has the potential to immerse the learner in various situations (the surface of the Moon or a delicate strand of DNA molecule), collaborate with people thousands of miles away (in adventure educational games or projects), visualize information (the temperatures of a frontal system), or even bring museum artifacts to the hands of the learners.

Only recently have educators working with K-12 students begun to explore the educational possibilities of VR learning environments (Byrne, 1996; Gay, 1994; Osberg et al., 1997; Youngbutt, 1998). Hay and Barab (Barab, Hay, Barnett, & Squire, 1999; Hay & Barab, 1998; Hay et al., in press) have been researching students using generic VR construction tools to build VR solar systems and conceptual understandings of astronomical phenomena. One exciting opportunity of these new technologies is the practice of scientific modeling (Jackson, Stratford, Krajick, & Solloway, 1994; Lehrer, Horvath, & Schauble, 1994; Roth, 1998).

The methods and processes of inquiry through computational-modeling bring new challenges and opportunities for science educators (Stratford, Krajick, & Soloway, 1998; Lehrer, Horvath, & Schauble, 1994). From a learning perspective, the act of modeling allows students to engage in a design process, beginning with a set of tentatively accepted theories and evolving into coherent understandings as represented in their models (Roth, 1996; Sabelli, 1994). In contrast to showing students models designed by others, many current modeling initiatives support students in constructing their own models (Hay et al., in press; Roth, 1998). While constructing models, a "conversation" unfolds in which robust interactions occur between the student, their model and the materials (inscriptions) of their work, as they attempt to create meaning through and from their constructions (Roth, 1996). Through participation in this process, students move beyond simply reading facts to be memorized, and instead, become involved in an iterative process in which their understandings inform the development of their models and the evaluation and testing of their models inform evolving understanding (Barab, Hay, & Barnett, 1999).

Activity theory

Activity Theory is a psychological theory with a naturalistic emphasis that offers a framework for describing activity and provides a set of perspectives on practice that interlink individual and social levels (Engeström, 1987, 1993; Leont'ev, 1974; Nardi, 1996). Although new to Western researchers, Activity Theory has a long tradition as a theoretical perspective in the former Soviet Union (Leont'ev, 1974, 1981, 1989; Vygotsky, 1978). In Activity Theory, the "subject" is given higher ontological status than tools in determining the nature of the activity, with other factors mediating the subject's particular transformation of an object. When discussing activity, activity theorists are not simply concerned with "doing" as a disembodied action, but are referring to "doing in order to transform something," with the focus on the contextualized activity of the system as a whole (Kuutti, 1996; Engeström, 1987, 1993). The "minimal meaningful context" for understanding human actions and the transformations they produce is the activity system, which includes the actor (subject) or actors (subgroups) whose agency is chosen as the point of view in the analysis and the acted upon (object) as well as the dynamic relations among both (Barab, in press).

These relations among subject and object are not direct; rather, they are mediated by various factors, including tools, community, rules, and division of labor (see Figure 1) (Engeström, 1987, 1993; Kuttii, 1996). By subjects, we are referring to the individuals or groups whose agency is selected as the point of view for the analysis. Objects can be raw materials, conceptual understandings, or even problem spaces "at which the activity is directed and which is molded or transformed into outcomes with the help of physical and symbolic, external and internal tools" (Engeström, 1993, p. 67, italics in the original). The "community" of a system refers to those individuals and/or groups who share the same general objects, and are defined by their division of labor and shared norms and expectations. Specifically, divisions of labor can run horizontally as tasks are spread across members of the "community" with equal status, and vertically as tasks are distributed up and down divisions of power. Lastly, all activity systems are somewhat constrained by the formal (systematic, general, and expected), informal (idiosyncratic adaptation), and technical (mandated and, potentially, written) rules, norms, and conventions of the "community" (Hall, 1959).

[insert Figure 1 about here]

The components of activity systems are not static components existing in isolation from each other, but are dynamic and continuously interact with the other components through which they define the activity system as a whole. From an activity theory perspective, an examination of any phenomenon (e.g., learning in the classroom) must consider the dynamics among all these components. In addition to these interactions of an activity system of a particular time and space, it is important to note that an activity system is made up of nested activity systems. For example, although the computer may serve as a tool in one activity system, at an earlier time this computer may have been an object or an outcome of a previous activity system. In a similar fashion, technical rules that affect a current activity system (e.g., a judicial preceding) were the outcome of a previous activity system in which the technical rules were created.

The focus of an activity system is on how subjects transform objects, and how the various system components mediate this transformation. With respect to the role of technology, for example, activity theorists are concerned with how these tools mediate the relations between subject and object. Therefore, it is not simply the human-computer (subject-tool) interaction that is fundamental to understand, but the subject-object interactions as mediated by the computer that become crucial. This perspective expands the unit of analysis from the mind of the individual (as in traditional cognitive research) or from the human-computer interaction (as in traditional Human-Computer Interaction research, Carroll, 1987, 1991), to the entire activity system (context) (Barab, in press).

It has been suggested that activity systems are characterized by their internal primary and secondary contradictions (Leont'ev, 1978; Engeström, 1987, 1993). These contradictions are best understood as tensions among the components of the activity system. Engeström (1993) described primary contradictions as those that exist within a component of the system, while secondary contradictions exist among different components of a system (object versus tool). For example, in developing a framework for analyzing discoordinations in medical consultations, Engeström (1993) initially defined the poles (contradictions) along two axes. Along the x-axis he placed the medical and administrative authority versus the lifeworld of the patient, and along the y-axis he placed somatic-biomedical versus psycho-social explanations (Engeström, 1993, p. 82). These two central discoordinations led to secondary conditions between components (e.g., tools versus objects), as well as the defining of primary contradictions within each system component, for example, patients with ambiguous problems as quantity versus patients as life systems. Using this framework, Engeström (1993) was able to illuminate the tensions existing within doctor-patient relations, and to contextualize these tensions within the broader context of the medical field.

In addition to the primary contradictions within components of the system, Engeström (1993) also discussed secondary contradictions. For example, Engeström (1999) described the emerging activity system that he called <u>international activity-theoretical collaboration</u>, referring to a system of international group of scholars who created an organization to clarify the central issues of Activity Theory. He discussed the contradiction existing currently between the very challenging issues Activity Theory is facing and the rather weak instruments of collaboration and discussion at their disposal. Another contradiction for this group exists "between those challenging issues <u>and</u> the fragmented division of labor that keeps pulling different disciplines, national groups, and schools of thought apart, preventing joint discussion." As contradictions enter systems, they become the moving force behind disturbances and innovations, and eventually drive the system to change and develop.

Activity Theory has exciting implications as a non-dualist theory for describing the inseparability of learning and acting. In contrast to traditional theories that suggest learning is a precursor to activity or, the reciprocal, "activity (sensory, mental, and physical) is a precursor to learning" (Jonassen & Rohrer-Murphy, 1999, p. 64), Activity Theory avoids the above dualisms by conceptualizing learning as activity and activity as learning (Engeström, 1999). As such, distinctions between practice and understanding or between individual and "context" also become meaningless. For Activity Theory, the context is not simply a container nor a situationally-created experiential space, but is an entire activity system, integrating the subject, the object, the tools (and even communities and their rules and divisions of labor) into a unified whole (Engeström, 1993). As stated above, it is the sum of these components and the contradictions among them that influence the types of transformations a subject can have on an object. An examination of a course must address all these components as a system, as well as the inherent contradictions of the system. It is with these goals in mind that we turn to a discussion of the methodology used for the study.

THIS STUDY

General Research Agenda

In general, our research can best be described as naturalistic inquiry, with grounded interpretations based on both quantitative and qualitative data (Guba & Lincoln, 1983; Scriven, 1983; Stake, 1983). Data were collected over a two-year period through direct observation and field notes, the use of multiple video cameras directed at individual learning groups in a particular classroom, interviews with students and instructors, document and artifact analysis, and retrospective recall analysis. For the initial summer camp (8 males, 7 females) and the first two semesters of the course (Spring 98, 8 males, 2 females; Summer 98, 6 males, 3 females), we had one researcher and an accompanying video camera assigned to each group of students (four groups of two, four groups of three, and two groups of four). Researchers attended all of the classes (10 three-hour classes in the pilot, 25 one-and-a-half hour classes the next semester, and 15 two-hour classes over the summer), continually maintained notes, and when appropriate, posed questions to validate interpretations. In addition, we carried out interviews probing student understandings, and instructors were interviewed to confirm hypotheses made in weekly meetings.

Consistent with the work of Roth (1996) and Barab et al. (1998a), we collected data that: (a) documented practices (e.g., tool use, problem solving, student inquiry) and resources (e.g., concepts implemented, tools); (b) captured the discussions among students and between students and teachers; (c) documented the progress of student projects; (d) traced the same students, artifacts, actions, and procedures over time; and (e) supported and refuted emerging hypotheses about how practices, resources, task constraints, task manifestations, and student understandings evolved over time. The issues were continually refined during fieldwork, group meetings, and increasingly focused data collection and analyses. In constructing and triangulating interpretations (Lincoln & Guba, 1986), we used field notes, interviews, document analysis, previously-developed case studies, and data coded using the Constructing Networks of Activity approach.

Constructing Networks of Activity (CNA). Barab, Hay, and Yamagata-Lynch (1999) developed a methodological approach, CNA, to identify important interactions and tracing the historical development of various phenomena (practices, artifacts, understandings, issues). Using the CNA methodology, data analysis involves first videotaping all interactions, and then "chunking" the data into discernible units of analysis that are referred to as "nodes." A node, minimally, contains information about the issue at hand (theme), who the initiators are, who the participants are, what practices the initiators are engaged in, and what resources are being used. The next step is to record information related to the specifics that constitute each node. This, thus far, has resulted in the creation of two rich databases containing thousands of coded nodes of information that can be searched to identify targeted interactions.

In analyzing the data for this study, we will select various actors (students, instructor), tools, practices (tool and concept related), student productions (e.g., projects developed), and conceptual understandings (e.g., understandings of eclipses, instructor practices, project expectations) and then use the database and fieldnotes to identify where in the course they emerged. Based on the node descriptions in the database and tags in our fieldnotes, we then go to the original videotapes and examine the complete dialogue. Through an examination of the dialogue, we are able to develop an appreciation for the course context in which this particular set of interactions occurred.

Activity Theory

Using Activity Theory as our theoretical lens, we will examine the relations of subject and object as mediated by the primary components that constitute an activity system: (a) tools (both technological and human), (b) the overall classroom microculture (emergent norms), (c) division of labor (group dynamics and student/instructor roles), and (d) rules (informal, formal, and technical). Given that activity systems are characterized by inner contradictions, the first step in applying this theory as an analytical tool involves clarifying the primary contradictions that characterized the course activity system. For this study, our goal is to identify the primary contradictions that characterized the overall course and to use these contradictions as a framework for more focused analyses of specific, momentary interactions during the course. In identifying these contradictions, we examined field notes, interview data, pre-post interviews, and used the database to identify important interactions for review using the class videotapes. As central issues emerged, we looked through these multiple data sources so as to triangulate our interpretations. Lastly, member checks with the course instructor and previous students were used to further substantiate that these were indeed central tensions of the course.

Using the emergent framework, it is our intention to examine course instances to serve as exemplars of the broader course tensions and innovations, as well as to provide evidence that our course supports learning. For reporting the data in this paper, field notes and the database of interactions will be used to identify instances related to the primary contradictions identified as characterizing the course. In addition to the field notes and database descriptions, we will review the coded instance on the videotapes, allowing us to better contextualize the instance being discussed. Engeström's (1987) triangle will be used to define the component structure of each of these instances of activity[1]. Following the reporting of these nested systems, we will characterize the results through a more generalized depiction of the activity system, one that is abstracted from its concrete form (Leont'ev, 1974).

THE VSS COURSE

The Virtual Solar System (VSS) project is an experimental undergraduate astronomy course initially taught at a large midwestern university and now being expanded to a southeastern university as well. In the VSS course, listening to lectures is replaced by students building VR models of different aspects of the solar system using CosmoWorlds, a VRML editor. The curriculum was developed collaboratively by an astronomy professor, two educational

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[1] It is our contention that the overall course structure is a macro-reflection of each of these nested interactions, and, thus, we find it useful to apply the triangle at multiple levels of activity, both micro and macro. As others have argued (Knorr-Cetina, 1986; Latour, 1987), each macro-level unit of analysis can be conceived as a collection of nested micro-level units of analysis. It is partly toward revealing this nested level of activity systems that our results section is targeted. For example, we intend to capture how on one occasion the VR tool served as the object, only to be "black boxed," closed off for inspection, and used as a tool to enable the subject to have an object at a later date. Black boxed describes the process by which a piece of machinery or a set of commands becomes compiled. At this point, the commands are no longer the focus of the activity, but can be used, transparently, to perform some other activity.

psychologists, and a graduate student studying astrophysics and instructional systems technology.

Three projects were designed with the expectation that students would model various astronomical phenomena on their computers. These are outlined in detail in the course syllabus, passed out on the first day.

1) Project No. 1 is to model the Celestial Sphere. This project requires students to model fundamental astronomical concepts concerning the equinoxes, the solstices, and the ecliptic and the celestial equator. Students decide upon scaling parameters, discuss how their model compares with the real solar system, and generate viewpoints so that users can visualize the equinoxes and solstices from multiple locations.
2) Project No. 2 is to model the Earth-Moon-Sun system. This includes proper sizes, distances between objects, surface features, correct tilts of the bodies, and correct rotation and orbital periods. In addition, students are to provide a cut-away view or a transparent view that shows the interior structure of the Sun, Earth, and Moon.
3) Project No. 3 is to model the entire solar system, comparing and contrasting both the terrestrial planets and Jovian planets. Specifically, students are expected to make a model of the Sun, eight planets (Pluto and Ceres as options), six satellites (Moon, Galilean satellites of Jupiter, Titan, and Triton), the Saturn ring system, and with the option of adding comets and asteroids. Again, these bodies must have their proper orbits, sizes, colors, spin, tilt, distances, and interior structures.

The first step in a project is for the instructor to introduce the particular "seed" questions developed for the specific project (see Table 2). Student models are expected to address instructor- and student-developed seed questions related to important astronomical phenomena. The purpose of the seed questions is to help frame the development of a model around which these and other questions could be addressed. Each group negotiates plans to answer the questions, identifies resources (textbook, WWW, and scientists), designs and builds their models, evaluates them, uses them to demonstrate answers to the initial questions, and shares their models with other groups. In addition to these instructor-supplied seed questions, students are also expected to develop four to five questions of their own that their models will address. These questions are based on their research and revised throughout the modeling process, over the period of project development.

A second set of instructor-developed questions we call "base" questions, are introduced to each group, addressable with the same model, and serve the purpose of filling out the curriculum. However, unlike the instructor's seed questions that are given to all students before the model constructing process begins, base questions are presented to groups when they are ready, at the discretion of the instructor. Lastly, we have also developed a series of "enrichment" questions, in which students are expected to pose "what if" questions to their models, probing and challenging the depth of understandings. Unlike the seed and base questions, these questions are not introduced to each group, but are available to the instructor for groups that he perceives as capable of addressing, and potentially benefiting from, more advanced questions.

[insert Table 2 about here]

Each project has four concluding activities. First, teams create a joint paper describing the features of their model. Second, each student presents and explains their team's model to students from other groups in a cave automatic virtual environment (CAVE). The CAVE is a walk-in stereoscopic VR display device that creates a total immersion experience for the learner. Third, students engage in a group presentation in which they demonstrate the functionality of their model to the entire class, using an overhead display in the regular classroom. Fourth, students write individual papers that compare and contrast their projects with other projects in the class and with the characteristics of the real solar system. This is a vital step in their learning about the modeling process. It is our position that if students can articulate the difference between their models and the actual solar system, they will demonstrate an understanding of the astronomy they are describing at a deep level, as well as an understanding of modeling as a practice (see Confrey & Doerr, 1994; Sabelli, 1994).

Curricular Evolution. The curriculum for the VSS course is focused on the student construction of models to explore and evolve their understandings of astronomy. Though the basic tenets of the curriculum have remained the same since the course prototype, our series of design experiments has led to numerous curricular revisions (Hay & Barab, 1999). For example, in the VSS prototype, students were provided a description of model expectations and a list of questions from which the final exam would be derived. The model description and the examination questions, in essence, provided structure for the students, but relieved the students of formulating good research questions to explore through their models. Thus, the students in the prototype course frequently focused on the provided questions rather than exploring, asking their own questions, and designing models rich in astronomical concepts. Further, the students would simply attempt to construct a model that was a representation (typically a duplication of another model in a book or on the Internet) of the astronomical phenomenon they were studying at the time.

In the current course framework, we have abandoned the explicit description of what the first model must include, as well as the initial set of examination questions. Instead, the instructor uses seed, base, and enrichment questions in the manner discussed above to support students in developing their own model constraints. This curricular evolution, based on the results of our initial design experiments, resulted in exciting outcomes. First, it changed the professor's ability to answer the question, "How good do I have to make the model?" In the prototype course, it was a rather arbitrary judgement based on the professor's assessment of what the students could do in the given time frame. In the current courses, the answer is, "Good enough to answer the question(s)," thus, turning the question into an opportunity to further encourage the inquiry process. Secondly, the nature of the course changed from creating models as one would build a model car to display on a shelf into building models in the way a scientist would within a cycle of inquiry. Thus, students are now being guided to engage in the scientific inquiry process of problem posing, formulating, solving, and reflecting through the construction of their astronomical models.

Another important evolution relates to the challenges of learning the astronomy, while at the same time also learning the technology. It has been since the course conception our intention to contextualize the learning of the technology around the building of student models. As such, we did not want to take the first week teaching the technology, and then begin introducing astronomy at week two. However, in the Spring semester Project No. 1 immediately immersed the students in modeling the complex orbital dynamics of the Earth-Moon-Sun system as they were learning the technology. As such, students were overwhelmed, for example, trying to place "viewpoints" in their model when the object they wanted to move would be constantly changing its location in three-dimensional space. To address this problem, we added the Celestial Sphere as the first project. This has helped address student frustrations because the model is relatively static, providing an anchor point from which students can gradually build their technology skills. Then, when they begin modeling the orbital dynamics of the Earth-Moon-Sun system they already have a base of understanding of the technology that lessens the dramatic learning curve that emerged in the Spring semester.

RESULTS AND DISCUSSION

Based on our large corpus of data, it became apparent that there were two primary contradictions that characterized the course. Member checks with the course instructor and former students were used to further validate that these were indeed central tensions of the course. The first dimension of difference and dispute that emerged from our data was the role of the instructor in supporting the learning process. This contradiction involves whether it was the instructor or the students who determined what is to be learned and what steps are taken to promote learning (Barab, Squire, & Barnett, 1999). Specifically, it is the tension between teacher-centered, pre-specified instruction on one end and student-directed, emergent learning at the other end that constitutes our first contradiction of interest. The second primary contradiction of focus arose from the fact that we incorporated cutting-edge technology into the course design. This tension was first apparent in the course development, in which the astronomy professor expressed concern over the fact that learning the technology and building VR worlds would take time away from learning astronomy (Hay, Johnson, Barab, & Barnett, in press). During data collection and data analysis, especially in the Spring semester, we also identified instances in which there was tension between building VR models and learning astronomy. Combining these two dimensions resulted in a framework for examining the potential of the VSS course to support learning (see Figure 2).

[insert Figure 2 about here]

Using this framework, we will now turn to specific examples that provide grounded instances of the overall course activity system. In presenting the issues, specifically, we will begin with concrete examples from the classrooms. These examples are selected based on their being representative of the interactions that emerged with respect to a particular contradiction. Each example will begin with a brief description of the context surrounding the transcribed section of data. Following the context and transcribed section, we will use Engeström's triangle to analyze the specific instance of activity, our interpretation of the instance, and how it relates to the overall class activity system. These interpretations will be "triangulated" with other data, including pre- post-test interviews targeted toward identifying student conceptual understandings

(Lincoln & Guba, 1986). Lastly, we will draw more general interpretations, conceptualizing the findings with respect to implications.

Contradiction I: Learning Astronomy versus VR Models

The first contradiction of focus is on whether building VR models interfered with the students' learning of astronomy. In examining this contradiction we will provide examples that are representative of the larger course, and that illuminate both when building VR models facilitated learning astronomy, and where it appeared to interfere.

Interrelations of VR Models and Astronomy Understanding

Using Models to Understand the Line of Nodes. In this example, Todd is talking to the instructor about the difficulty he is having understanding when eclipses occur, and how to represent them. The instructor suggests that Todd should look at Erica's (a student from another group) VR model and see how she used the concept of line of nodes to demonstrate when eclipses occur. The dialogue below picks up when Todd asks Erica how she used line of nodes in her VR model.

Activity A

1. Todd There is a rumor that you're working on the line of nodes in your model. I'm not sure what it is.
2. Erica It's where the plane of the ecliptic between the sun and earth, and the plane of the earth and moon intersects…It is not a real line…Whenever the moon crosses this line [pointing to the screen] there is an eclipse…[Todd nods]

Activity B

3. Erica [pointing to the screen, continues] The way I made mine, I made a long cylinder and made it a very long line.
4. Todd Wow, that thing is a cylinder!
5. Erica Yeah, [pointing to a line on the screen]…I grouped the earth and the line of nodes so the line of nodes would stay with the earth when it revolves.

Activity C

6. Todd That's a good idea. So what you are trying to demonstrate here is when the line of nodes come together…That's when the eclipse happens…That's

good…Wow!

7. Erica Yeah this is going to be neat…When I did it last time I grouped it wrong, so be careful.

8. Todd Thanks!

The above description of our data portrays how multiple activities are nested within each other for a common anticipated outcome. Todd, the subject who is engaged in the above activities, is determined to obtain a better understanding of when eclipses occur to fulfill the technical rule of the A100 class to represent eclipses in the VR model. Initially, Todd is interested in obtaining the object of understanding when eclipses occur, and asks the instructor who becomes the tool for mediating the subject to obtain the object. Within this activity, even though Todd's overall goal is to understand and represent when eclipses occur in his VR model, we see how Todd has broken down his goal to understanding the concept of when eclipses occur and put aside the goal of representing it in his VR model. The instructor, as mediator, suggests Todd consult Erica, who has a representation of the line of nodes in her VR model, so that he can better understand when eclipses occur. Therefore, the outcome of this activity is to direct the subject to a new tool (Erica and her model) for obtaining the anticipated outcome.

Todd then engages in series of activities centered around Erica and her VR model, with the model serving as the object of understanding as well as the tool in supporting understanding the concept. Figure 3 is a graphical representation of Todd engaging in activities A to C to obtain the anticipated outcome. Throughout these multiple activities, Todd is interested in obtaining different objects in each activity, but is anticipating to obtain the outcome of understanding when eclipses occur. Initially, Todd (subject) presents himself to Erica (tool) wanting her to mediate his understanding of the astronomical concept of line of nodes (object). In the dialogue that constitutes Activity A, Erica provides an explanation of her understanding of the line of nodes and proceeds to introduce her model as another tool for Todd's mediation. As Todd listens to Erica's explanations and examines her model, he begins to develop his own understanding of line of nodes. Todd's new understanding is mediated by engaging in an activity with Erica, all of which becomes black boxed (no longer to be questioned) and is nested as a mediating tool in Activity B.

[insert Figure 3]

In Activity B, Todd (subject) focuses on obtaining the object of understanding Erica's VR model, and how she represented the line of nodes. In order for Todd to obtain this object he uses his newly developed understanding of the concept of line of nodes. This depicts that a whole activity experienced by a subject prior to a newly encountered activity can become one of the components, nested, within the next activity system. Within our scenario, this does not guarantee that Todd has obtained a rich and accurate understanding of the concept of line of nodes, but it demonstrates how a subject can choose to use a newly obtained object regardless of its richness for mediating another activity. In Activity B, Erica points to her model and shows Todd what technical strategies in CosmoWorlds she used for representing the line of nodes. This helps Todd to have a further understanding of the concept of line of nodes; he expresses this appreciation with "Wow!" In Activity C, Todd explains to Erica his new understanding of line of nodes, and how it relates to when eclipses occur. Therefore, in Activity C, Todd's new understanding of line of nodes, Erica, and her model all becomes the tool for him to obtain the object of understanding the relationship among the line of nodes, when eclipses occur, and representing it in a VR model.

The similarities and differences between a full moon and a lunar eclipse are elusive astronomical concepts for introductory students. In the pre-class interviews, only one student articulated a satisfactory explanation of the difference between a full moon and a lunar eclipse as having to do with the tilt of the Moon's orbital plane. Todd, a student with minimal science background, demonstrates his confusion with the cause of lunar eclipses in the following sequence:

Interviewer: When do we get a lunar eclipse?

Todd: I think it has something to do with the day/night sequence. I guess that when the Earth is turning, we see different sides of the Moon.

In his post-interview statement, Todd utilized two conceptual tools developed during the VR modeling process, the five-degree tilt of the Moon's orbital plane and the line of nodes, to explain the reason for lunar eclipses.

Todd: The Moon is going around the Earth and the Moon is behind the Earth and the Earth is going around the Sun. The ecliptic and the rotational path intercept at the line of nodes and due to the five-degree tilt, they cross at certain points. If it is a total eclipse than it

> is an umbral eclipse it is beet-red, if it is a penumbral eclipse, then it is partial eclipse. It depends on when the Moon is on the line of nodes.

Todd arrived at a rich conceptual understanding of lunar eclipses. In a similar fashion, by the end of the course, seven of the eight students utilized the concepts of the Moon's orbital tilt and the line of nodes to explain the Earth-Moon-Sun system. The active engagement of the students in modeling the system in three dimensions forced them to confront the often-overlooked phenomenon of the Moon's orbital tilt. Furthermore, the concept of the line of nodes became a central component of all the models. The incorporation of the line of nodes in their models allowed the teams to predict when a lunar eclipse would occur as distinct from a full moon. The concept of the line of nodes is usually reserved for advanced astronomy courses. In the context of the virtual astronomy course, it became a valued tool for building a model that accurately portrayed eclipses. In this example, the object, a VR model of the Earth-Moon-Sun system, required the conceptual tools, tilt of the Moon's orbital plane and the line of nodes, to bring about the desired learning outcome, a rich conceptual understanding of how full moons and lunar eclipses are similar and different.

Understanding the Sidereal and Synodic Periods. The sidereal and synodic periods are important astronomy concepts that were the focus of the first project. In Activity A of this example, Erica was not sure where and how to position the camera in CosmoWorlds for the viewpoint setting in order to demonstrate the sidereal and synodic periods. In Activity B, Erica decided that she wanted to explain the difference between the sidereal and synodic months to the instructor and her partner Kathy.

1. Erica All right, I wanted to make sure that I understand the sidereal and synodic thing so I can explain it, but I am not sure if I can.
2. Instructor Go for it.

Activity C

3. Erica OK, [starts drawing and referring to her notebook paper] when the earth , OK this is the Earth, Sun, and this is, like, the constellation that the Earth sees the Sun in.

Activity D

4. Erica OK, so for the Sun to reach the same place and see against the stars like in

one day is like the sidereal period?

5. Instructor Right, it's the time it takes …to move in a month measured in fixed position.

6. Erica OK, but because the Earth is still rotating as that day is going by, it for instance won't be at noon when that happens, so the time noon to noon is synodic.

7. Instructor Exactly.

8. Erica OK, I'm not…I guess I pretty much understand it. Do you? [asks Kathy].

Activity E

9. Once Erica finishes the conversation with the instructor about her understanding of the sidereal and synodic months, she starts a conversation with her partner Kathy on how to demonstrate them in their VR model.

10. Erica OK, now to show that [points to the computer] in our model we need one camera for it to see, like, a phase of the moon, like, one month to the next, then we need one above…so we can…huh…

11. Kathy So you mean there is more than three?

12. Erica Which three?

13. Kathy The three viewpoints. Where would you place that? We are fine with this point [points to paper], I don't know about that, and another one would be this point, right, actually….

14. Instructor It depends upon which you want to demonstrate.

15. Erica It looks like the month would probably be easier.

The above description of our data depicts the multiple activities that the subject, Erica, engages in to obtain the anticipated outcome of understanding and representing the sidereal and synodic months in her VR model. This outcome is one of the technical rules presented to the A100 class by the instructor. In this example, the object that the subject obtains throughout the multiple activities A to E are different, but they are all focused toward the anticipated outcome (motive) of understanding and representing the sidereal and synodic months (see Figure 4).

[insert Figure 4 about here]

In Activity A, Erica confronts the tension between how to technically manipulate the viewpoint settings in CosmoWorlds, and how to model her understanding of sidereal and synodic months. The object that the subject obtains in Activity A is "how to use the VR tool to represent sidereal and synodic months." In Activity B, Erica pursues the object of "testing her understanding of the two astronomical concepts" where the instructor becomes the tool that mediates Erica's decision making, prompting her to test her understanding with the words “Go for it” in Dialogue 2.

In Activity C, Erica articulates her current understanding of sidereal and synodic months. She begins her explanation by engaging in an activity of obtaining the object of a "paper and pencil sketch of the Sun and the Earth." The tool that the subject uses in Activity C is her current understanding of the relationship between the Sun and the Earth.

Once Erica finishes drawing her sketch of the Sun and Earth on the piece of notebook paper, she refers to it as a tool in Activity D while explaining her understanding to her instructor, who is the other tool in this activity. Through Activity D, Erica obtains the object of "confidence in her own understanding of the sidereal and synodic months." Once Erica is confident that her understanding is accurate, she focuses her attention to how to use viewpoint settings in CosmoWorlds to represent her understanding in her model. She uses the instructor, Kathy, her sketch, her model, and CosmoWorlds all as tools to obtain her object of "strategies for setting viewpoints to demonstrate sidereal and synodic months" in her VR model.

Contradictions of VR Models and Astronomy Understanding.

The Tool as Object. The following discussion shows how tensions were created and were eventually resolved between understanding astronomy and working on models in the VR course. Kurt and Randy are struggling to create and animate viewpoints to show the Moon’s eclipse. They have omitted one step in the animation process, which is causing CosmoWorlds to reposition their objects. Both of them are unaware that they have skipped this key step, and are confused as to why CosmoWorlds is “moving” objects.

Activity A

1. Kurt So you didn’t get it back to the right place?
2. Randy What happened there? I don’t understand. Is that the Earth and Moon?

3. Kurt I don’t know. Why do these things keep moving? Why don’t they just do it on the Y? It’s real frustrating.

4. Randy 4.3 5.0

5. Researcher What do you want to do?

6. Kurt We want to spin this around that. This is the Earth Moon this is the Sun. The problem is that every time we do this thing, numbers just appear from nowhere that you didn’t put in, you know? You don’t put in anything, you don’t move anything. It’s so frustrating to me. It’s really bothering me. [pause for a few seconds, as Kurt works with his model]. So that’s right, but now what? See that one [the viewpoint] wasn’t even there last time. It was point something. Now, it’s [CosmoWorlds] made something else up. So the distance is right. Where did these [distances created by CosmoWorlds] come from? So now I’m gonna change it down to zero. [pause] Not to mention that the scale to size is whacked out every time. I don’t know if I should change them, or just assume they’re right. I don’t know where they get these things, because I never put those numbers in, you know?

In this segment, we see how the VR tools become the object of the activity. Kurt is clearly struggling to understand how to use the tool. He would like to model the Moon’s eclipse. He knows precisely where the viewpoint cameras should go, but is unable to physically place them in the desired position. He is quite frustrated, as his inability to use the tool is interfering with his ability to build his model and demonstrate astronomical concepts. The next passage exemplifies the group’s frustration.

7. Kurt: Can I drop this class? [Then, to the computer] C’mon please?

8. Randy: This is a lot harder class than the other two astronomy classes I took. No one helps.

9. Kurt: If you move it, it’s gonna get messed up. (Pause for 20 seconds) How are you doing, Alan?

10. Alan: OK. How are you doing?

11. Kurt: [Kurt gives him the “thumbs down” pauses.] “Very frustrating.

CosmoWorlds won't do anything I tell it to do."

In Activity A, Kurt is struggling with the tool and object CosmoWorlds (see Figure 5, Activity A). As a result of this frustration, the outcome, he publicly considers dropping the course. Randy seems to agree, and adds his dissatisfaction about the amount of support available in the course. In commenting that CosmoWorlds "won't do anything I tell it to," Kurt shows that CosmoWorlds is the object of his activity. He is trying to learn to use CosmoWorlds as a tool. However, due to his lack of experience, CosmoWorlds is simultaneously the object and the tool of this activity.

[insert Figure 5 about here]

Understanding viewpoints played a critical role in the modeling process. Over the course of the project, Kurt became skillful at placing viewpoints and using CosmoWorlds as a tool to develop his model. With this newly-developed skill, Kurt spent the first thirty minutes of the next class (Activity B), using the animation editor of CosmoWorlds to add viewpoints to his model. As the model approached completion, Kurt began to shift his focus from building the model to enhancing the model in depicting astronomical phenomena. In the following passage, Kurt is using viewpoints along with the animation editor to demonstrate astronomical concepts in his model. Kurt has just set a viewpoint on Mercury looking out towards the solar system.

Activity C

12. Kurt: No way, that is so cool. Hey, look [to Mandy] you know what's happening?
13. Mandy: [says nothing]
14. Kurt: All the others are standing completely still and Mercury is spinning.
15. Mandy: Oh, that's awesome!
16. Kurt: Finally, something you can see, you know?

In Activity B, Kurt (the subject) used CosmoWorlds (the tool) to complete his VR model (the object). Following this, in Activity C, Kurt the subject has begun using his VR model as a tool to explore astronomical concepts. By setting a camera on Mercury, he made the model demonstrate how quickly Mercury is spinning, and how quickly it revolves around the sun. Through this activity, he has taken a relatively static concept from the textbook and explored its dynamic relationship with respect to the solar system through the model. In other words, using the model has allowed him to visualize the concept of Mercury's day and year. Over the next two days, Kurt created 23 other viewpoints designed to highlight astronomical phenomena, including the Pluto and Charon system, Neptune's unusual elliptical orbit, the relative size and distances of the planets, and the relative length of each planet's day and year. Thus, expanding the model beyond just a static depiction of the planets to include viewpoints allowed Kurt to develop a robust understanding of orbital relationships as the <u>outcome</u> of Activity B.

<u>Modeling Scale</u>. The following dialogue illustrates how students decided to create multiple models to represent eclipses and phases of the Moon.

<u>Activity A</u>

1. Instructor So how is your scale model going?
2. Jessica It is going OK, but look at this. We have used the Earth's diameter to help us scale them [the Sun, Moon and Earth], but we can't see anything!
3. Instructor Have you tried to line them up on the X-axis and zoom out to try to see them?

<u>Activity B</u>

4. Steve No, we haven't, but still the Moon is so far away from the Earth. I don't think we can show anything about the eclipses or phases.
6. Instructor You could try a different scale.

<u>Activity C</u>

7. Jessica But we have worked so long on this one.
8. Steve Is it possible to use a different scale for the sizes and the distances?
9. Instructor You can, but just make sure you acknowledge the shortcomings in your model.
10. Steve Sure, we can keep the one to scale and use this one [the model not to scale] to present.
11. Instructor OK, sounds good to me, just remember the shortcomings of your model.

The <u>technical rule</u> of this project was to demonstrate phases of the Moon and eclipses as part of a scaled model of the Earth-Moon-Sun system. From this rule, a tension emerged between creating a model that demonstrated phases of the moon and eclipses on the one hand, and on the other hand, an accurate representation of scale. In this example, we see how the subject, Team Yellow, struggles with this tension. In Activity A, Team Yellow recognizes the inadequacy of the scaled model in representing eclipses and the phases of the moon (see Figure 6). After examining the accurately scaled model, which is the tool in Activity B, the subject decides that they need a re-scaled model that would represent eclipses and the phases of the moon. In Activity C, the subject obtains a strategy for creating a model that does not accurately represent all aspects of scaling, but does represent eclipses and the phases of the moon. In this example, the outcome of the activity system is the subject's recognition that two models are needed to represent all relevant astronomy concepts.

[insert Figure 6 about here]

In the course there was a contradiction between fostering student development of VR models that represent, demonstrate, or explain some astronomical phenomenon, and the students constructing a compromised model which appears aesthetically pleasing. This contradiction is not always desirable, as it proved to be detrimental to some students' comprehension of astronomy. For example, the Earth-Moon-Sun system project involved modeling the distance and size relationship among the three objects. However, the above dialogue illuminates how when students constructed their model to scale, they were uncomfortable with the results because the model, though accurate, was not very easy to see and explore on their desktops.

Therefore, students frequently either compromised the astronomical accuracy of their original model (as occurred above), or developed one model for class presentations and one that was conceptually accurate (also occurring above). This procedure of creating two models did indeed allow the students to construct models that looked aesthetically pleasing, and did have utility in representing astronomical concepts. For example, as evident in Todd's description above, students successfully modeled and, in post-test interviews, competently answered questions regarding how eclipses occur and whether the Earth has phases when viewed from the Moon. However, most students maintained an inadequate appreciation of the distance scale between objects in the solar system. For example, Jessica never went beyond a tenuous understanding at post-test:

> Interviewer: So far we have a scale of the size of the planets, is that the scale of distance?
> Jessica: No.

Interviewer: Say the Sun was that size [the size of a grapefruit], how many planets could I fit on these two boards?

Jessica: I could guess, like, big time. Oh gee, in my model I had to make the Sun smaller because it was eating Mercury. When I did it to scale, I couldn't even see Mercury. And that was almost the same. I'm just completely guessing. [<u>she spreads out the objects in the classroom</u>] I'm basically just spreading them out evenly.

Interviewer: How many planets could you get on these two boards if drawn to the scale to the Sun?

Jessica: To scale, I don't think we would get very far unless we cut down the scale. With the Sun that big. I think we might get to Mars because there is a lot of space in between there. There are big distances, I know that.

The above dialogue clearly illuminates Jessica's limited understanding.

Another student, Dave, also had an aesthetically pleasing but astronomically inaccurate model, and struggled with issues of scale in the post interview.

Dave: [Going to the white board]. Do you want the scale of size?

Interviewer: Well, I really want the scale of size and the scale of distance, but tell me what you think. How would you do it? So if you were to draw the Sun that big, how many planets would you fit distance-wise in this room?

Dave: [Struggling with scale.] I'd probably take it to that door to draw it correctly. Because we were trying to do it correctly in our model and it was just impossible. We had to completely change scale because…

In the quote above, Dave expresses his frustration trying to model the scale of the solar system with CosmoWorlds. Given the vast distances between planets, the student groups were forced to compromise the accuracy of their model to be able to present a visually pleasing, monitor-screen size presentation. This resulted in an impoverished appreciation for the scale of the solar system by four of the eight students in the post-test interviews

<u>Contradiction 2: Pre-Specified, Teacher-Centered versus Emergent, Student-Directed Constraints</u>

The second contradiction is centered on the tension with respect to the origin of course constraints. On the one hand, it was our intention to support student ownership, and on the other, we clearly had specific astronomy knowledge that we intended that students learn. In examining this contradiction, we looked at instances in which students did not develop constraints, as well as those instances in which task constraints did emerge.

Pre-specified, Inert Expectations and Shared Labor

Failed Project From Poor Planning. As a general rule, the students begin the first project by defining their own methods and means of reaching their final goal. For example, during the first project, student groups just proceeded ahead, paying little attention to planning their tasks and to division of labor. However, over time, the instructor suggests that the students keep a record of their progress, the facts being used to construct the model, and the data of their model such as the position of their planets in the model. The instructor also suggests that the project would probably be most efficiently done if the groups divide tasks.

Activity A

1. Beth I think we should probably work together, because that way we will always know what each of us is doing.
2. Kate OK. Any ideas on what we need to do?
3. Beth No, I guess we probably should read and find out about the Earth.
4. Kate OK.
5. Instructor [about 10 minutes later] How are you doing? Do you have any questions concerning the project?
6. Beth No, though I think we are going to work together first, because it looks like we can make a better project with both of us working on the same thing.

Activity B

7. Beth Something is wrong with our project, we can't move the Earth.
8. Instructor Do you know the position of the Earth?
9. Beth No, we have moved its center to the Sun and it only says 0,0,0. [showing her frustration]
10. Instructor OK, let's see if we can figure it out. Do you know the position of

your Sun?

11. Kate I think it is at 0,0,0.

12. Instructor OK, now do you have the position of the Earth written down?

13. Beth No.

14. Kate That would probably have helped us.

Activity C

15. Instructor Yes, maybe in the future you should, because it will solve problems like you are having now and it is good scientific practice.

16. Beth Well, what do you think we should do? Maybe just start again, but this time keep the data.

17. Instructor Has your team decided on who would be the note taker?

18. Kate No, I guess I can be.

19. Beth OK, then let's just start over and this time we will write everything down!

Activity D

20. Team [Students then proceed to work on their model with Kate as notetaker.]

In Activity A, to fulfill the technical rule of working in groups, the subject (Team Blue) in collaboration with the instructor and each other (the tools) try to develop a project plan (the object). Then in Activity B (below), Team Blue recognized the need to develop a project plan. In Activity B, the subject (Team Blue) was frustrated with the tool (CosmoWorlds), because it was hampering their ability to create the object (VR model). This frustration led the team to consider keeping a record of their work. In Activity C, they consult with the instructor (the tool) to create team roles (the object). Lastly, in Activity D we see how these new roles and rules feed back into this new iteration of the student activity system.

[insert Figure 7 about here]

The above dialogue is an example of the more general finding that, overall, groups did not plan for their first project. Instead, the projects were haphazard, incomplete, and received lower grades than did the second and third projects. Using the database, we found that for the Spring semester, students had only 22 nodes related to planning during the first project and 144 nodes for the second project. Further, in the first project, students did not begin planning until day four, while in the second project they had 25 nodes related to planning at the same point. To some degree, these results suggest that our hope of students' developing their own constraints was not actualized in practice. However, based on their experience with the first model, students took ownership and proceeded in a more systematic manner for Project No. 2.

Emergent Expectations and Distributed Division of Labor

Developing a Plan. In the first project, students worked collaboratively to develop a model of the Celestial Sphere. However, there was little systematic planning and students expressed dissatisfaction with the quality of their first model. Kurt summed up his experiences in Project No. 1, “I’m not very excited about this one, but the next one has to be better.” The dialogue below describes the beginning of the second project.

Activity A

1. Kurt OK, I have put down everything I think we need to do to complete the second project. Is there anything I am missing?
2. Instructor I can't think of anything, it looks very good.
3. Mandy OK, so you have the scales of the planets already done too?
4. Kurt Yes, I just used the table in the book and multiplied those numbers by 10.
5. Instructor Sounds good.

Activity B

6. Mandy OK, so what do you want me to do?
7. Kurt It depends. What do you want to do?
8. Mandy Let me see that [pointing to the document]. I think I want to do Saturn, and maybe Jupiter.
9. Kurt OK, I will work on a scale model.

In Activity A. Kurt, the subject, is using his textbook and mathematical skills as tools to create a table of scaled distances for their model, the object (see Figure 8). The table of scaled distances shifts from being the object in Activity A to being a tool in Activity B. Using this table, the subject, Team Orange develops a strategy to divide tasks, the object. This led to the overall work plan, the <u>outcome</u>. This document became a formal plan, as well as influenced future division of labor.

[insert Figure 8 about here]

The assignment of the tasks to individuals, though a good practice for accomplishing tasks as team, was not as successful for fostering the development of a broad understanding of astronomy. For example, during the post-test interviews, several students could not describe the composition of Jupiter, because a different team member was solely responsible for investigating and modeling the interiors. The following excerpt is taken from a student's post-test interview:

Interviewer:	Could you describe to me the structure of Jupiter? That is, what is the composition of Jupiter?
Steve:	Hmm, good question.
Interviewer:	Did you model Jupiter? Or was that your partner?
Steve:	She did the work for that. I don't really know. I think it has gas, rocks. I know it has clouds. Well, hmm, I remember reading something about Jupiter being Hydrogen. I remember, Mike [the instructor] saying that if Jupiter was a little bigger it would be a star. There you go.

<u>Class Expectations Regarding Presentations</u>. At the end of each project, student teams were expected to present their models to the entire class. The students were encouraged to focus on the astronomy content in their models during the presentations. Initially the presentations were not considered a vital part of the project by the students. Consequently, there was little evidence of planning. According to the instructor, all groups delivered sub-standard presentations for Project No. 1. Following their presentations, most groups met to discuss their concerns about the quality of their performance. In the dialogue below, team members plan their presentation for the second project. It is evident from the dialogue that their previous presentation was unsuccessful, and that this proved to be part of the impetus for the increased preparation for the second presentation.

<u>Activity A</u>

1. Taro	OK, we have to get ready for the presentation. What are we going to do?
2. Todd	We should describe your logarithm scale, because that is different. I don't think other teams did it.

3. Taro OK, don't worry. I can do that.

Activity B

4. Taro How about your model?

5. Todd It is OK, I would like it to be better.

6. Taro Yes, but can you explain it? Let's see if you can. Tell me about it.

Activity C

7. Todd These planes represent, well let me think, the ecliptic, and the Moon's orbit I think.

8. Taro OK, but why?

9. Todd I was going to discuss the line of nodes!

Activity D

10. Taro [Asking Bob] Are you are going to present the Sun? What do you know about it?

11. Bob I know, and I have read the book.

12. Taro Let's find more [begins looking up the Sun in his textbook]. We need a good presentation. Do you know what this is? [pointing to a figure showing a photon’s path out of the Sun]

13. Bob OK, I know about that, it is the random walk thing that you told me about.

14. Taro OK, sounds good. It has to be better than last time.

15. Todd I sure hope so. The last presentation was terrible.

Post-Presentation

16. Taro [shaking Todd’s hand] Much better, much better.

17. Todd Yes, it sure is much better.

In Activity A, the subject, Team Green, is discussing their VR model and scaling methods, the tools, for satisfying the formal rule that every presentation, the object, has unique aspects (see Figure 9). Although the group does not discuss their previous problematic presentation until lines 14 and 15, this experience clearly is driving the planning and preparation of their current presentation. This discussion continues in Activity B where the subject Todd is trying to articulate his understanding of the model, the object, with the help of Taro, the tool. In Activity C, Todd identifies the plane of the ecliptic and the line of nodes, the tools, as the critical astronomy concepts for his understanding, the object, for a successful presentation, formal rule, that describes the model. In Activity D, Bob, the subject, is being challenged by Taro, the tool, to explain his understanding of his model of the Sun. Taro, the tool, assists Bob in locating more information in the textbook, a tool, for the intent of preparing a successful presentation, the object. As shown in lines 16 and 17, this set of activity systems led to the outcome of a self-satisfying presentation.

[insert Figure 9 about here]

CONCLUSIONS / SUMMARY

There are many different transformations that a subject can cause to undergo on an object. To some degree, it is the subject's goals and intentions that provide boundary conditions, constraining which particular affordances (opportunities for action) of the object the activity will transform (Barab et al., in press). However, the relations between subject and object are also mediated by various factors, including tools, community, rules, and division of labor (see Engeström, 1987, 1993). All these factors influence learner intentions as well as provide additional constraints. They simultaneously enable and limit relations between subject and object and the potential transformations and understandings of an object (Barab, in press). For this course, we focused on the relations of subject and object and how object transformations led to robust scientific understandings. These transformations were mediated by tools (both technological and human), the overall classroom microculture (emergent norms), division of labor (group dynamics and student/instructor roles), and rules (informal, formal, and technical). Of primary concern were how these factors supported the subject's transformation of astronomy content into virtual models and into rich understandings.

Instead of detracting from the emergence of an activity system that supported learning astronomy, the building of VR models frequently constituted learning astronomy. For example, we continually witnessed where the constructing of students models (the object) or the use of models as tools to visualize an astronomy concept (the object) served as a process of learning astronomy. This was evident in the first example where it was apparent that Todd's working on modeling the line of nodes helped his understanding of eclipses. Todd even referred to this model in the post-test when asked to describe why eclipses occur. This is not to imply that there was no tension. For example, we saw the increasing frustration expressed by Kurt and Mandy in which Kurt expressed a desire to drop the class. However, this was in the Spring semester, and the introduction of the Celestial Sphere project in the summer (discussed above in the Curricular Evolution section) may have lessened the frustrations surrounding learning the technology. This is partly because students modeling the static, Celestial Sphere did not have to learn the technology while at the same time having to model dynamical interactions. Our examination of the data suggested that by the summer session, the struggle between learning astronomy and learning technology was not a predominant feature of the course. This can also be credited to the development of seed and base questions whose answering required students to build models that embodied complex astronomy concepts. As a result, the models frequently served as a shared object through which collaborative learning was supported.

With respect to the tension between pre-specified, teacher-directed instruction and emergent, student-directed learning, the component that most directly influenced the course activity system was the object, suggesting that our course should not be conceived of as student-directed or teacher-directed, but as object-directed. This was evident, for example, in the fact that most of the groups did not begin planning until Project No. 2 when it became apparent that this was necessary if they were going to produce high quality models for presentation. These objects provided a shareable object, serving to constrain course activity towards those practices that most effectively supported the transformation of the object. In setting up this system of object transformation, it is the responsibility of the teacher to seed the system's emergence and to support students in developing their own constraints (Barab, Squire, & Barnett, 1999). This was partly accomplished through student-developed questions to be addressed by their models, but also involved the continual support of the teacher who used his astronomy expertise to push the object transformations in a manner that was consistent with those practices being advocated by the scientific community.

Reflecting on the above analyses, we interpret the various course tensions and innovations in the framework of the overall course activity system, modeled in general form in Figure 10. In this figure, we found the primary contradictions of the course to be characterized in the form of dilemmas within each component of the triangle (e.g., subject: passive recipient vs. engaged learner). The three secondary contradictions — a, b, c — all originate in the object component, indicating that the tension of, and between, building VR models and learning astronomy were the primary factors that contributed to the emergence of the secondary contradictions. More importantly, we argue that this tension (and innovation) forming around the object provided the central impetus for the evolution of the activity system. For example, rules, norms, and divisions of labor arose from the requirements of building and sharing VR models, not because they were teacher-imposed or because students aspired toward organization.

[inert Figure 10 about here]

IMPLICATIONS

We are witnessing a period in which we are moving from cognitive theories that emphasize individual thinkers and their isolated minds to theories that emphasize the situated nature of cognition and meaning. In general, situative perspectives suggest a reformulation of learning in which practice is not conceived of as independent of learning and in which meaning is not conceived of as separate from the practices and contexts in which they are developed (Greeno, 1998; Lave & Wenger, 1991; Resnick, 1987; Young, 1993). In the development of our course, we have accounted for the contextually-bound nature of cognition by situating learning within the context of a rich activity system (see Figure 10). As such, the outcome of learning is not simply the memorization of abstracted content and meanings generated by someone else. In the traditional course, the primary instructional activity is directed by the instructor who lectures to the students, with the students considered the object of change. In contrast, we have immersed (situated) the learner in an activity system that we argue differs from those present in traditional classrooms, and, at least from a situated perspective, will result in the development of richer understandings.

The focus of developing rich activity systems in which students participate in the making of knowledge has exciting educational implications for science education in particular, and education more generally. When educators present black boxed, scientific truths (the outcomes of someone else's activity system), they provide little opportunity for students to participate in the making of science. "The more the teacher, the curriculum, the texts, and the lessons 'own' the problems or decompose steps so as to push learners away from owning problems, the harder it may be for them to develop the practice" (Lave, 1997, p. 33).

In our course, we (the designers, the instructors, the students) work to establish an environment that supports students in building astronomy models and understandings. It is essential that designers concern themselves with how to support the emergence of activity systems that allow students to own the outcomes, and to support students in constructing outcomes that are scientifically accurate. The role of the instructor is to seed the emergence and facilitate the continual evolution of a system whose function is directed towards activities that support learning the material in question (Barab et al., in press; Barab & Mojica, in press). It is these goal-directed activities that constitute the central focus of the course curriculum.

In this research, we used Activity Theory to provide a lens for understanding the course contradictions and how they constituted the emergent activity system of the course. Determining which goal-directed objects will best support the emergence of robust systems is the challenge for instructional designers and educational researchers alike. In this paper, it was our intention to use Activity Theory to illuminate how our course supports the emergence of activity systems that transform objects through which students, as subjects in these systems, develop deep and meaningful understandings. The contradictions between understanding technology versus understanding course content and between teacher, pre-specified instruction versus emergent, student-directed instruction provides useful framework for characterizing technology-rich courses designed to support learning.

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Table 1. Central Features of TRIPLE-GU.

1. A central component of these environments is the use of technology as a tool for facilitating inquiry and/or other forms of authentic practice.
2. These environments must provide an opportunity for students to inquire into the phenomena they are learning.
3. Rather than telling students about practices, our environments are designed to support students in participating in domain-related practices.
4. These environments are intentionally designed to support the process of learning.
5. It is our intention to establish rich environments (studios, workshops, construction spaces) where students work collaboratively, not isolated classes or places to listen to lectures.
6. These environments are intended to immerse students in a context that grounds their understandings to meaningful activity.

Table 2. Seed, Base, and Enrichment Questions for the Earth-Moon-Sun System.

Seed Questions: Initial questions to start the project off.

1. What is the relative size and scale of the Earth, Moon and Sun?
2. What are the conditions necessary for phases of the Moon and Eclipses?
3. How does the Sun shine?
4. What are the differences and similarities between the Earth, Sun and Moon interior and atmospheres?

Base Questions: Questions that every student should answer after or during the construction of their models

1. Where is the Moon when it is full, new and quarter in relation to the Earth?
2. What is rotation and revolution rate of the Moon?
3. What effect does the Moon's revolution and rotation rate have on its appearance?
4. What is the ecliptic, and what is the Moon's position relative to the ecliptic?

Enrichment questions: Questions that are individualized to each group based on their capabilities.

1. What is the difference between the sidereal and synodic month for the Moon?
2. What is the line of nodes, and what does it tell us about eclipses?
3. Does the Moon have seasons?
4. Does the Sun set when viewed from the Moon?

Student-Generated Questions

1. How often do we get a solar eclipse?
2. How big does the Moon look from the Earth?
3. What would happen to the Earth's seasons if the Earth was tilted on its side?

Figure Captions

Figure 1. The basic structure of human activity. The figure illustrates the mediated relationship between subject and object, and the interrelations among the various components of the system.

Figure 2. Framework for examining the potential of the VSS course to support learning.

Figure 3. Using models to understand the line of nodes section.

Figure 4. Understanding The sidereal and synodic periods.

Figure 5. Activity system depicting contradictions of VR tools and astronomy understanding.

Figure 6. Activity system depicting contradictions of VR Tools and representing accurate astronomy concepts.

Figure 7. Activity system depicting poor planning and a failed project.

Figure 8. Activity system depicting the development of a plan.

Figure 9. Activity system depicting preparing for a presentation.

Figure 10. Primary and secondary contradictions of the course activity of students participating in the VSS course.

Figure 1

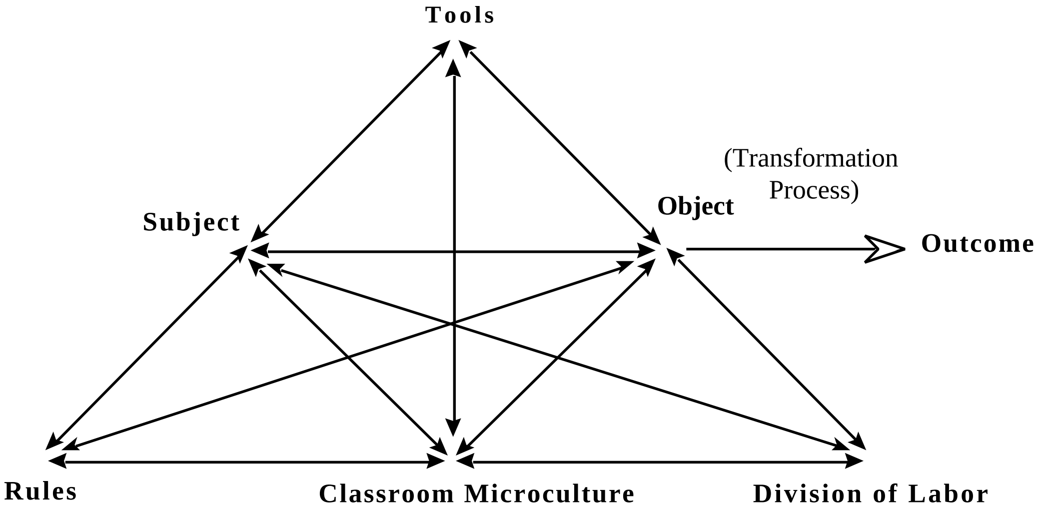

Tools
Subject
Object
(Transformation Process)
Outcome
Rules
Classroom Microculture
Division of Labor

Figure 2.

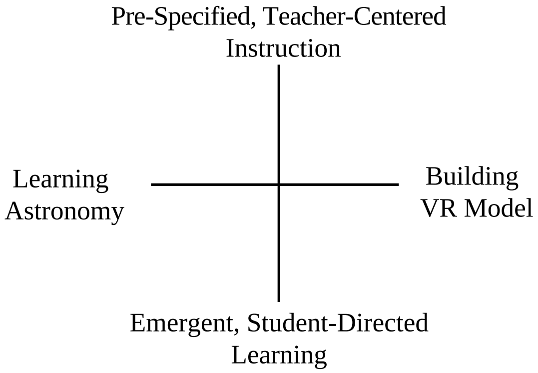

Pre-Specified, Teacher-Centered Instruction
Learning Astronomy
Building VR Model
Emergent, Student-Directed Learning

Figure 3.

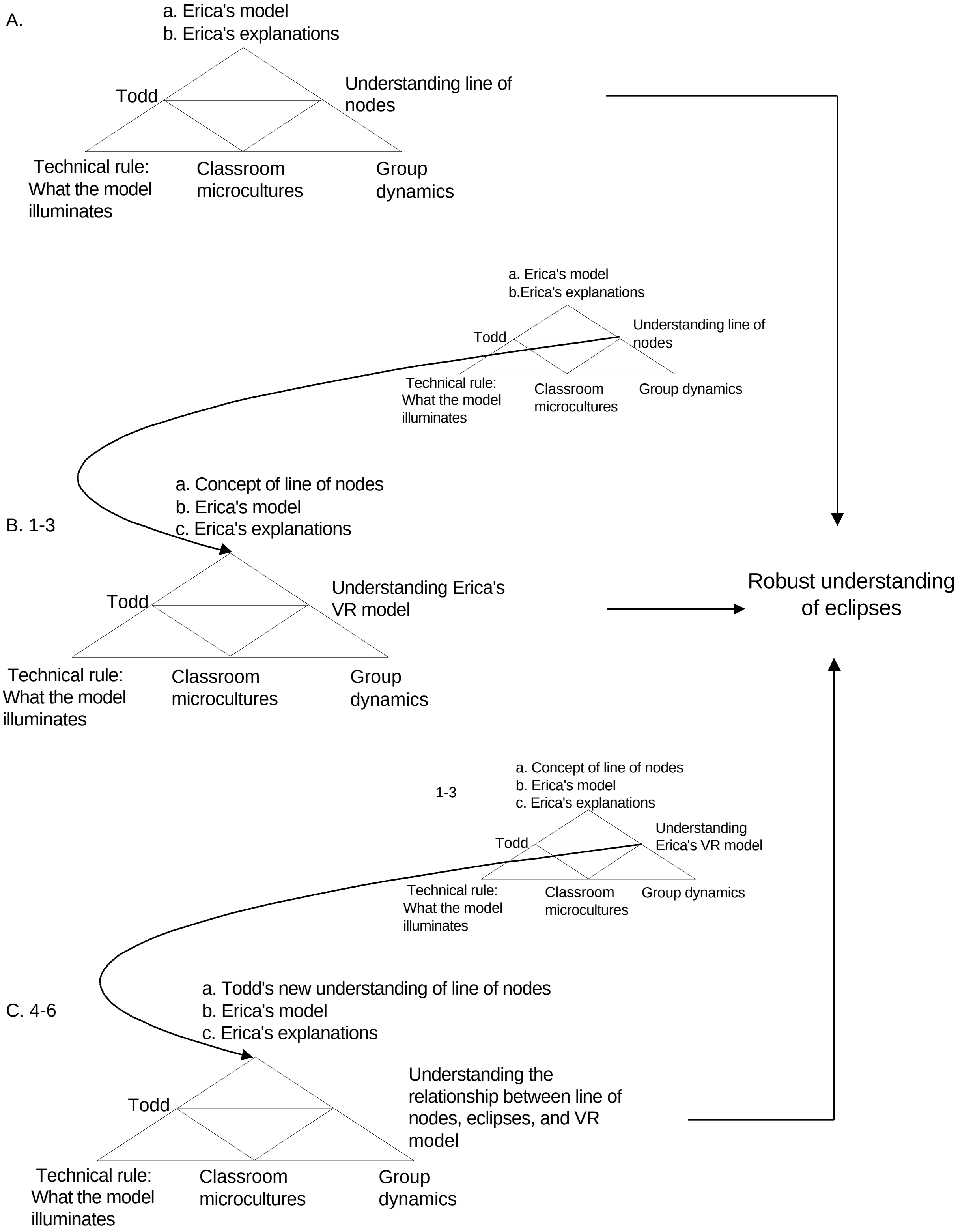

A.
a. Erica's model
b. Erica's explanations
Todd
Understanding line of nodes
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
a. Erica's model
b.Erica's explanations
Todd
Understanding line of nodes
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
B. 1-3
a. Concept of line of nodes
b. Erica's model
c. Erica's explanations
Todd
Understanding Erica's VR model
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
Robust understanding of eclipses
1-3
a. Concept of line of nodes
b. Erica's model
c. Erica's explanations
Todd
Understanding Erica's VR model
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
C. 4-6
a. Todd's new understanding of line of nodes
b. Erica's model
c. Erica's explanations
Todd
Understanding the relationship between line of nodes, eclipses, and VR model
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics

Figure 4.

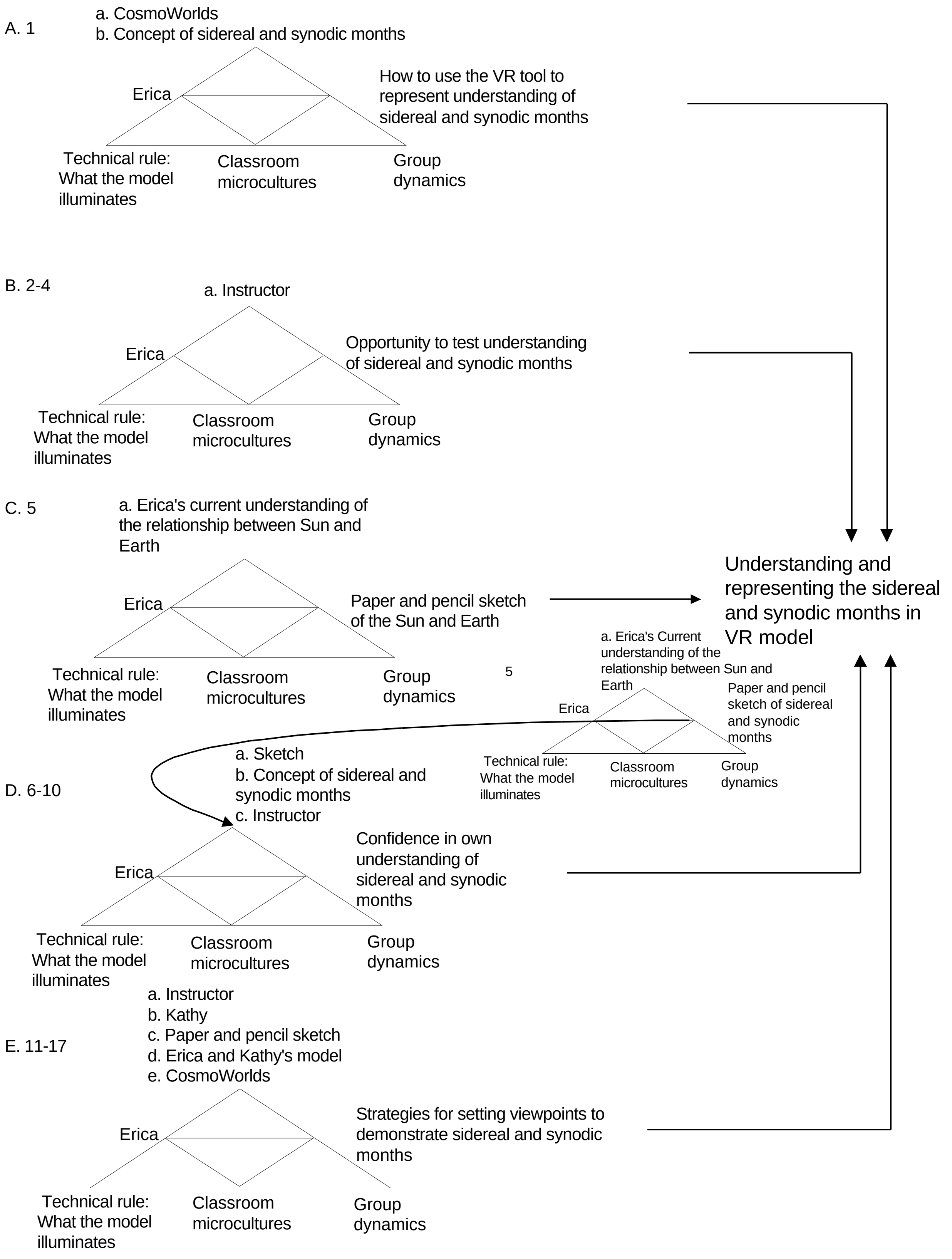

A. 1
a. CosmoWorlds
b. Concept of sidereal and synodic months
Erica
How to use the VR tool to represent understanding of sidereal and synodic months
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
B. 2-4
a. Instructor
Erica
Opportunity to test understanding of sidereal and synodic months
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
C. 5
a. Erica's current understanding of the relationship between Sun and Earth
Erica
Paper and pencil sketch of the Sun and Earth
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
Understanding and representing the sidereal and synodic months in VR model
5
a. Erica's Current understanding of the relationship between Sun and Earth
Erica
Paper and pencil sketch of sidereal and synodic months
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
D. 6-10
a. Sketch
b. Concept of sidereal and synodic months
c. Instructor
Erica
Confidence in own understanding of sidereal and synodic months
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
E. 11-17
a. Instructor
b. Kathy
c. Paper and pencil sketch
d. Erica and Kathy's model
e. CosmoWorlds
Erica
Strategies for setting viewpoints to demonstrate sidereal and synodic months
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics

Figure 5.

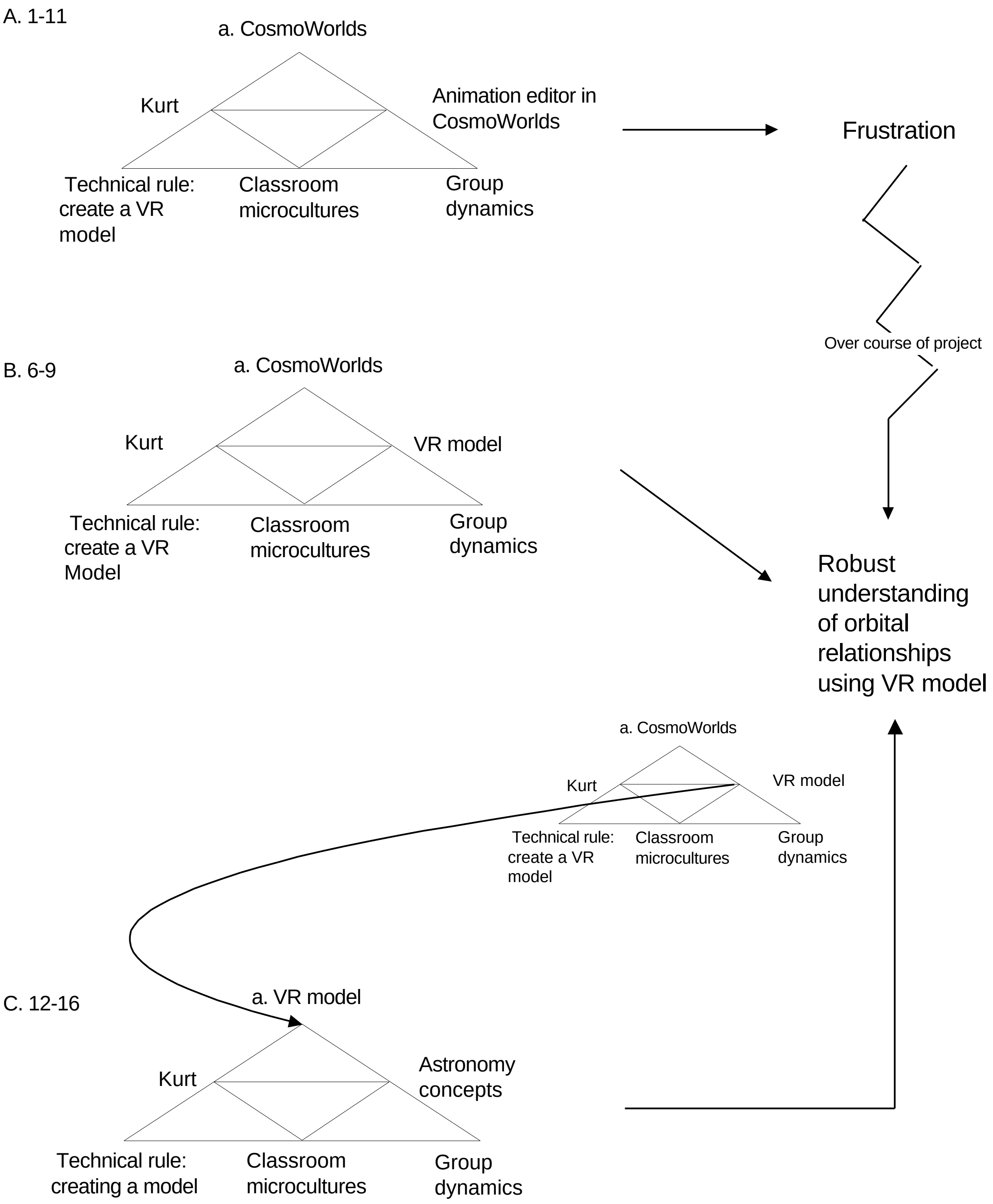

A. 1-11
a. CosmoWorlds
Kurt
Animation editor in CosmoWorlds
Technical rule: create a VR model
Classroom microcultures
Group dynamics
Frustration
Over course of project
B. 6-9
a. CosmoWorlds
Kurt
VR model
Technical rule: create a VR Model
Classroom microcultures
Group dynamics
Robust understanding of orbital relationships using VR model
a. CosmoWorlds
Kurt
VR model
Technical rule: create a VR model
Classroom microcultures
Group dynamics
C. 12-16
a. VR model
Kurt
Astronomy concepts
Technical rule: creating a model
Classroom microcultures
Group dynamics

Figure 6.

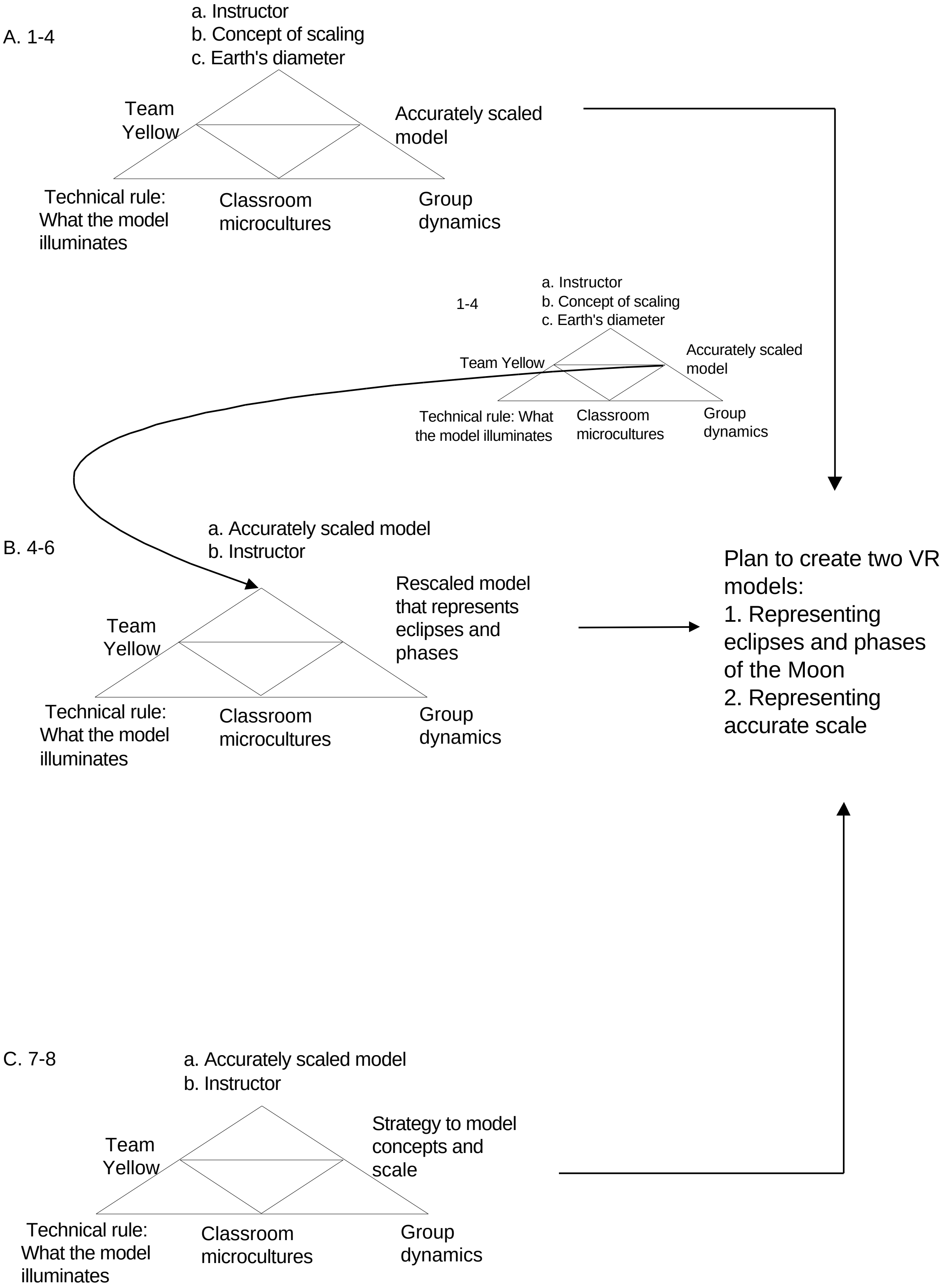

A. 1-4
a. Instructor
b. Concept of scaling
c. Earth's diameter
Team Yellow
Accurately scaled model
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
1-4
a. Instructor
b. Concept of scaling
c. Earth's diameter
Team Yellow
Accurately scaled model
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
B. 4-6
a. Accurately scaled model
b. Instructor
Team Yellow
Rescaled model that represents eclipses and phases
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
Plan to create two VR models:
1. Representing eclipses and phases of the Moon
2. Representing accurate scale
C. 7-8
a. Accurately scaled model
b. Instructor
Team Yellow
Strategy to model concepts and scale
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics

Figure 7.

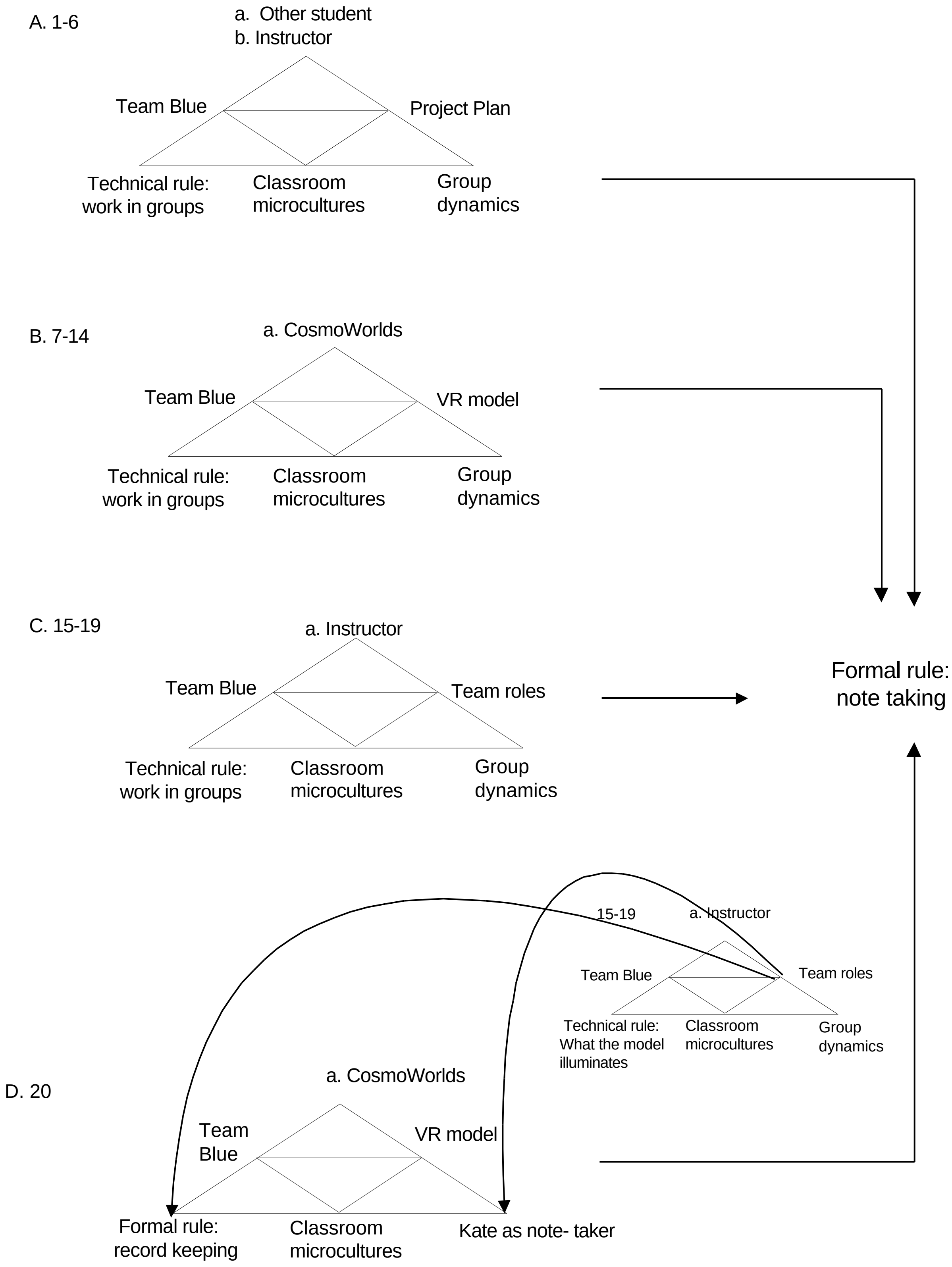

A. 1-6
a. Other student
b. Instructor
Team Blue
Project Plan
Technical rule: work in groups
Classroom microcultures
Group dynamics
B. 7-14
a. CosmoWorlds
Team Blue
VR model
Technical rule: work in groups
Classroom microcultures
Group dynamics
C. 15-19
a. Instructor
Team Blue
Team roles
Technical rule: work in groups
Classroom microcultures
Group dynamics
Formal rule: note taking
15-19
a. Instructor
Team Blue
Team roles
Technical rule: What the model illuminates
Classroom microcultures
Group dynamics
D. 20
a. CosmoWorlds
Team Blue
VR model
Formal rule: record keeping
Classroom microcultures
Kate as note- taker

Figure 8.

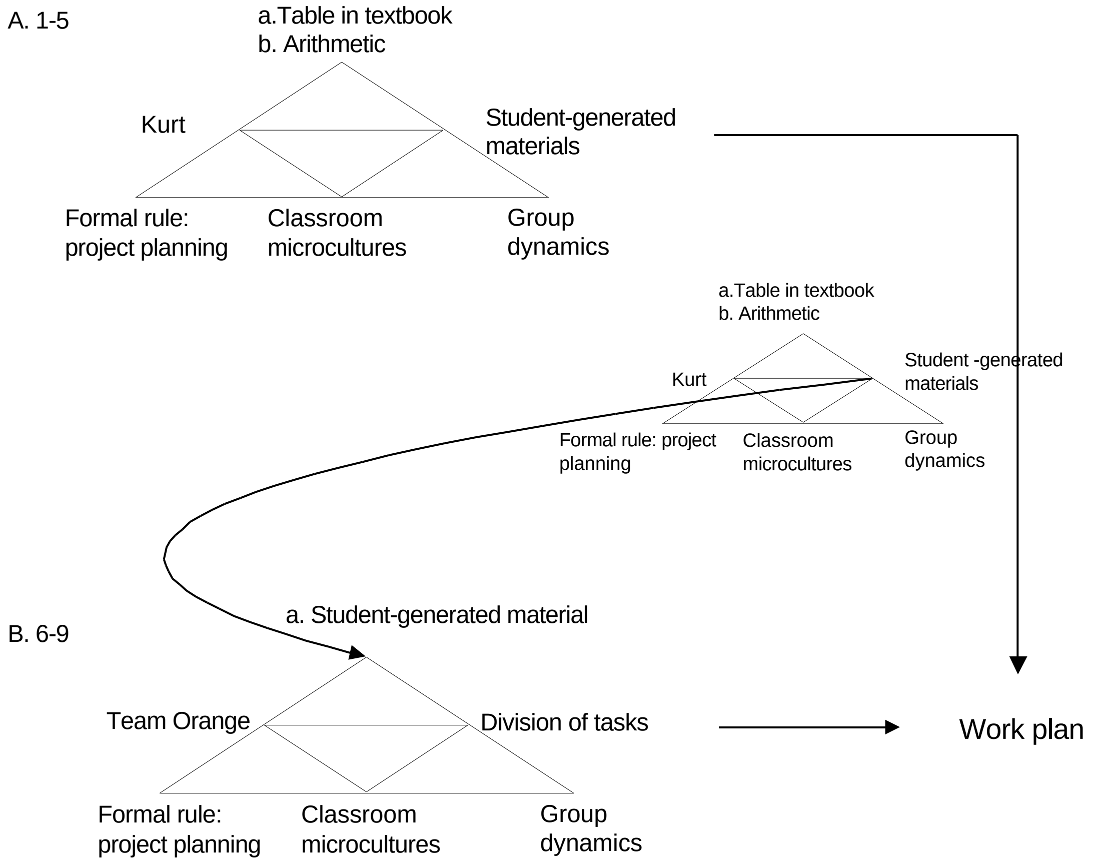

A. 1-5
a.Table in textbook
b. Arithmetic
Kurt
Student-generated materials
Formal rule: project planning
Classroom microcultures
Group dynamics
a.Table in textbook
b. Arithmetic
Kurt
Student -generated materials
Formal rule: project planning
Classroom microcultures
Group dynamics
B. 6-9
a. Student-generated material
Team Orange
Division of tasks
Formal rule: project planning
Classroom microcultures
Group dynamics
Work plan

Figure 9.

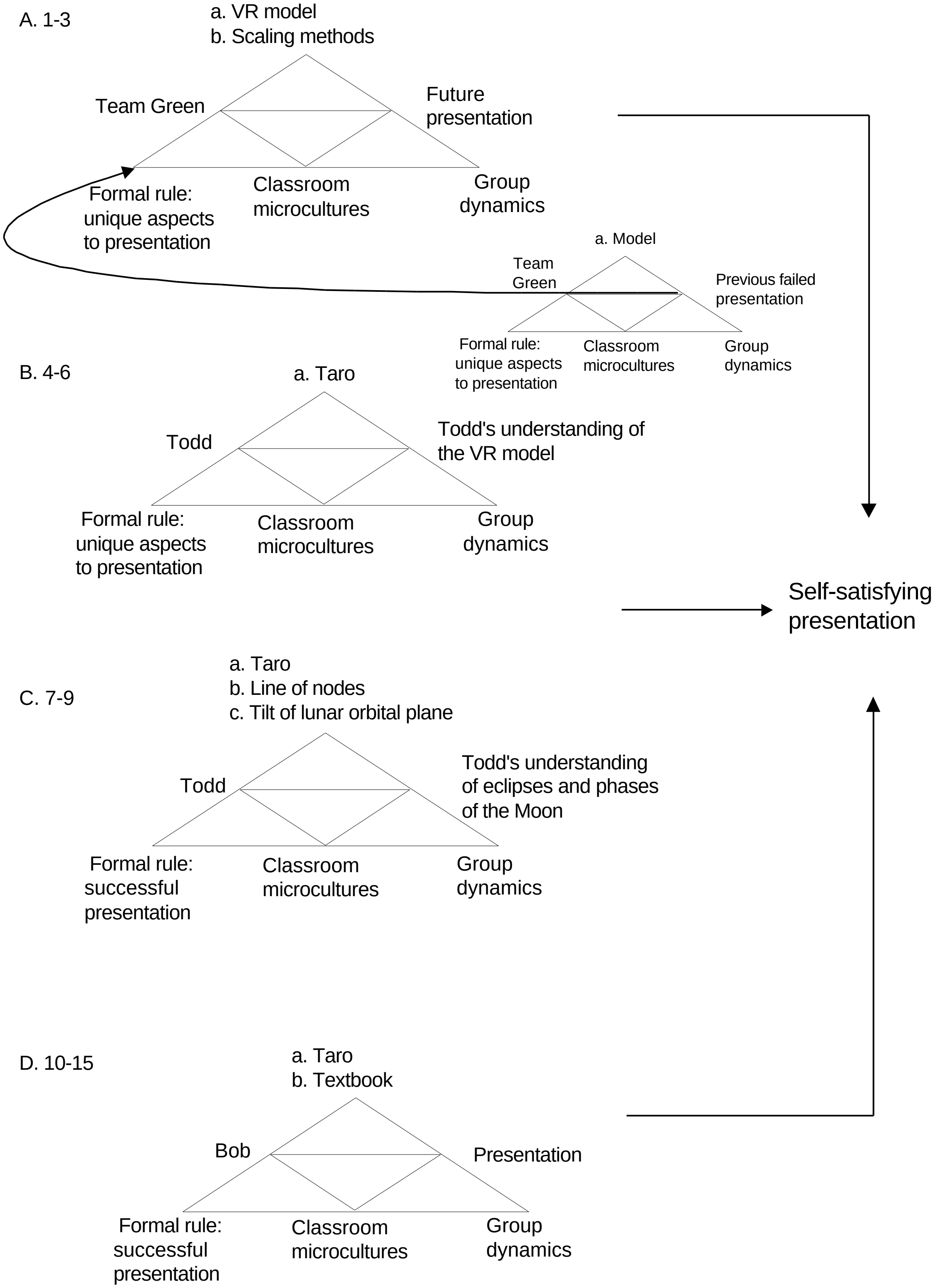
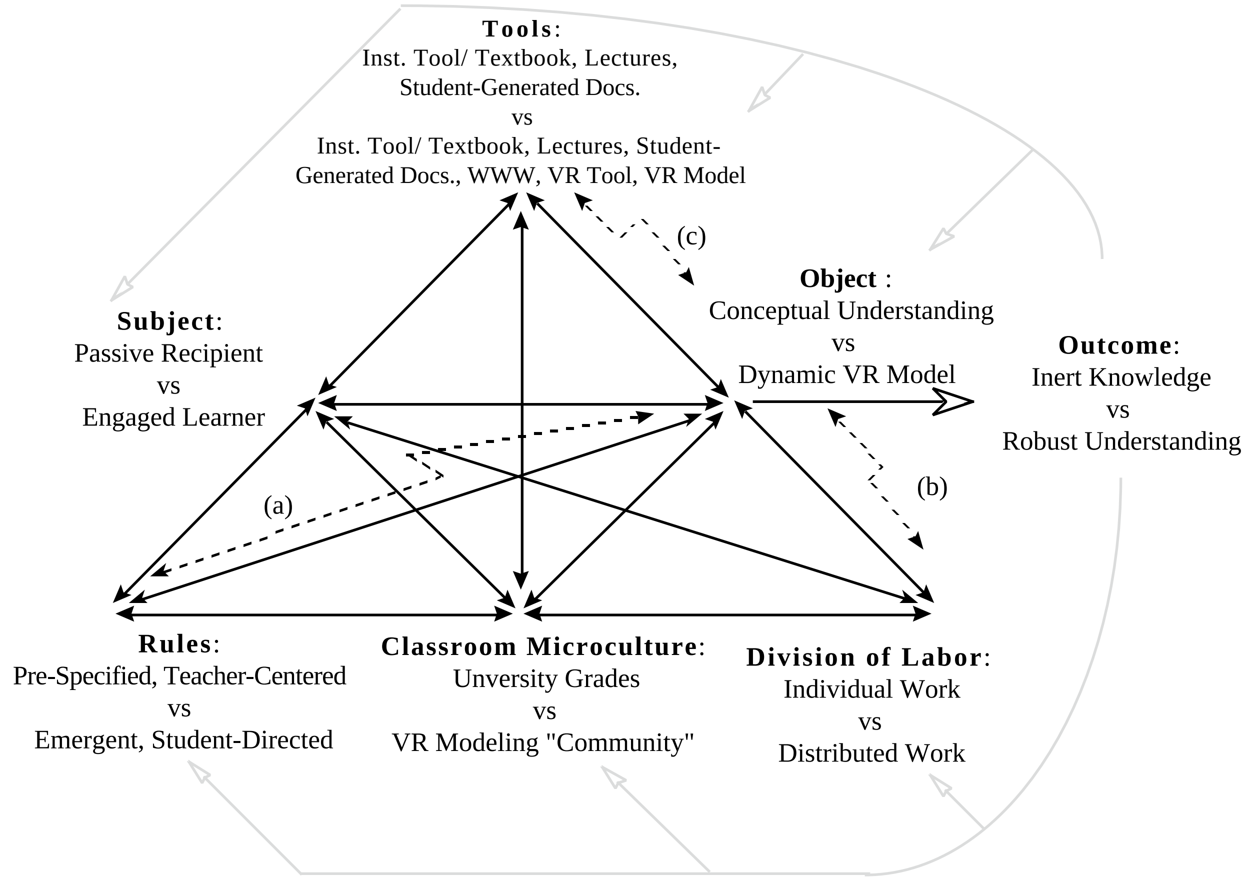

A. 1-3
a. VR model
b. Scaling methods
Team Green
Future presentation
Formal rule: unique aspects to presentation
Classroom microcultures
Group dynamics
a. Model
Team Green
Previous failed presentation
Formal rule: unique aspects to presentation
Classroom microcultures
Group dynamics
B. 4-6
a. Taro
Todd
Todd's understanding of the VR model
Formal rule: unique aspects to presentation
Classroom microcultures
Group dynamics
Self-satisfying presentation
C. 7-9
a. Taro
b. Line of nodes
c. Tilt of lunar orbital plane
Todd
Todd's understanding of eclipses and phases of the Moon
Formal rule: successful presentation
Classroom microcultures
Group dynamics
D. 10-15
a. Taro
b. Textbook
Bob
Presentation
Formal rule: successful presentation
Classroom microcultures
Group dynamics

Figure 10.


Tools:
Inst. Tool/ Textbook, Lectures, Student-Generated Docs.
vs
Inst. Tool/ Textbook, Lectures, Student-Generated Docs., WWW, VR Tool, VR Model
(c)
Object :
Conceptual Understanding
vs
Dynamic VR Model
Subject:
Passive Recipient
vs
Engaged Learner
Outcome:
Inert Knowledge
vs
Robust Understanding
(a)
(b)
Rules:
Pre-Specified, Teacher-Centered
vs
Emergent, Student-Directed
Classroom Microculture:
Unversity Grades
vs
VR Modeling "Community"
Division of Labor:
Individual Work
vs
Distributed Work