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PERSONAL EXCURSIONS: INVESTIGATING THE DYNAMICS OF STUDENT ENGAGEMENT

ABSTRACT. We investigate the dynamics of student engagement as it is manifest in self-directed, self-motivated, relatively long-term, computer-based scientific image processing activities. The raw data for the study are video records of 19 students, grades 7 to 11, who participated in intensive 6-week, extension summer courses. From this raw data we select episodes in which students appear to be highly engaged with the subject matter. We then attend to the fine-grained texture of students' actions, identifying a core set of phenomena that cut across engagement episodes. Analyzed as a whole, these phenomena suggest that when working in self-directed, self-motivated mode, students pursue proposed activities but sporadically and spontaneously venture into self-initiated activities. Students' recurring self-initiated activities – which we call personal excursions – are detours from proposed activities, but which align to a greater or lesser extent with the goals of such activities. Because of the deeply personal nature of excursions, they often result in students collecting resources that feed back into both subsequent excursions and framed activities. Having developed an understanding of students' patterns of self-directed, self-motivated engagement, we then identify four factors that seem to bear most strongly on such patterns: (1) students' competence (broadly construed); (2) features of the software-based activities, and how such features allowed students to express their competence; (3) the time allotted for students to pursue proposed activities, as well as self-initiated ones; and (4) the flexibility of the computational environment within which the activities were implemented.

KEY WORDS: activity dynamics, interests, scientific image processing, self-directed, self-motivated engagement, student-initiated activities

1. INTRODUCTION

Student engagement with classroom material has been a concern of educators at least since the time of Dewey (1913). Much research has been dedicated to the matter in the intervening decades, and it is fair to say we have advanced our understanding of the issue of student engagement. Unfortunately, in spite of these advancements disengagement is reported to plague our classrooms (Newmann, 1992). The recent flurry of research activity in the area seems to reflect researchers' concern with the problem (e.g., Lepper and Cordova, 1992; Hidi and Harackiewicz, 2000; Volet and Järvelä, 2001; Engle and Conant, 2002).

This paper aims to contribute to the growing body of research on student engagement. Specifically, our primary goal is to document and explain the dynamics of students' activities as they work in self-motivated, mostly self-guided, relatively long-term pursuits. Using process data of individual students' activities, we uncover both similarities and more idiosyncratic patterns that characterize the aforementioned mode of engagement.

The context of our observations is a unit on scientific image processing, a subclass of scientific visualization systems. The activities making up the image processing unit were implemented on a open and extendible computational medium, and we will show how modifying and/or extending activities beyond our original intentions played out in sustaining students' engagement. Because many such extensions were proposed and initiated by students, exposing relationships between their self-initiated pursuits and the activities as framed by the teacher is a major focus of analysis.

Finally, as an effort to aid practice we identify features of the classroom environment that seemed to bear most strongly on the patterns of engagement we observed. In this regard, despite the particularity of the context of our work, we hope our analysis and results can inform the design of engaging learning environments, whether computer-based or not.

1.1. *Some Approaches to Student Engagement*

As one can infer from Hickey's (1997) extensive review of research on student engagement, a significant portion of studies in the area has been done by researchers in experimental psychology. Work within this tradition has focused on the relationship between one or more psychological constructs – e.g., goals (Ames, 1992), intrinsic (Deci, 1992) and extrinsic motivation (Pintrich and Garcia, 1991), interests (Krapp et al., 1992), and self-theories (Dweck, 1999) – and students' engagement with school material. Dweck's work may stand as an emblem for the kinds of methods and theories characterizing experimental psychology's treatment of the problem.

In a nutshell, Dweck proposes that sustained engagement is a result of one's adoption of learning goals, whereas disengagement is associated with performance goals. Students who hold learning goals regard intelligence as malleable and subject to effort (incremental theorists). For them, challenges and failure are just a sign that persistence and stronger effort are needed. Conversely, performance goals characterize students who see intelligence as a fixed attribute (entity theorists). Entity theorists seek positive judgments and avoid "looking dumb." As such, they tend to eschew classroom situations that require effort or which offer the potential for failure because these are exactly the contexts that threaten their self-image.

Typically, Dweck assesses students' theories of intelligence with an instrument (e.g., a questionnaire), which is administered prior to an experimental treatment. Students' theories of intelligence and associated goals are assumed to remain stable across the experimental session and perhaps across contexts and domains. In this regard, no effort is spent, for example, in teasing out the details of students' behavior during the experiment.

In fact, save for a few exceptions (e.g., Renninger, 1992) experimental psychology has been mute about the *processes* underlying student engagement (Paris and Turner, 1994). Furthermore, reliance on experimental situations has resulted in theories that ignore many of the complexities of real world classrooms. As a consequence, we have barely explored questions such as: How does student engagement develop over periods typical of lessons or whole units (e.g., days or weeks)? How does engagement emerge from the interactions among participants in a classroom? How does the material infrastructure available to students, analyzed in a moment-by-moment fashion, affect their ability to engage classroom material?

As a response to the lack of adequate attention to these questions, as well as a reaction to the methods and epistemological assumptions of experimental psychology (Hickey and McCaslin, 2001), a number of studies in the cultural-historical tradition have begun to analyze the processes whereby classroom engagement is fostered or hampered. Two such studies are Engle and Conant (2002) and Cobb and Hodge (submitted for publication).

Engle and Conant (2002) report on a study of groups of 4th and 5th grade students working on a unit on the biology of endangered species. In particular, their analysis focuses on *how* two such groups became passionately engaged in an argument about species classification, a topic that emerged as a problem bearing on the original assignment. In doing so, the authors attend to the arguments students have within and across groups, and how such arguments extend across sites and situations. By tracing the evolution of students' grappling with issues they raised themselves, Engle and Conant show how students' arguments build on their previous history and become increasingly sophisticated, thus setting a context for continued engagement.

Starting from a related methodological and theoretical stance, Cobb and Hodge (submitted for publication) use two statistical data analysis design experiments to investigate the process whereby 7th graders' mathematical interests may be cultivated. For the authors, students have developed a mathematical interest to the extent that they see mathematical activity as worthy of their classroom time. Furthermore, what constitutes mathematical activity is that which the classroom community continually negotiates as the norm. Patterns in the evolution of these norms point to the group's developing understanding of statistical analysis as well as to issues students judge to be of interest for continued investigation.

1.2. *Characterizing Student Engagement*

As used here, engagement refers to a quality of the relationship between an individual and an activity – including its broader "context," such as material and social infrastructures – as viewed in the actions or feelings of the individual. "High engagement" refers to situations where the individual: (1) would choose the activity, given a choice; (2) would persist in the activity, given a choice; (3) invests personal resources, such as effort, in the absence of coercion or outside incentives; and (4) has positive affect toward the activity.

Critical to the definition above is the idea that students might be allowed some latitude in choosing the activities with which they engage. In turn, if and when students do exercise choice, we may ask several questions of educational relevance: What is the resulting dynamics of student engagement? What might students learn while pursuing activities of their own making? Might these activities have a bearing on students' work on activities as framed by the teacher?

Briefly, our data suggest that, given the "right" conditions, students working in self-directed, self-motivated mode pursue framed activities but sporadically and spontaneously venture into self-initiated activities. Students' recurrent self-initiated activities, which we call *personal excursions*, bear some important relationship to the goals of framed activities, but do not fully align with them. Importantly, personal excursions appear to be key events whereby students connect, in a deep and personal way, to the subject matter and overarching goals of the unit. Indeed, personal excursions often result in students collecting resources (e.g., ways of working with the computational environment) that feed back into both subsequent excursions and framed activities. Rather than deeming these pursuits unproductive, therefore, we take them to be part of the life of an activity (Cole, 1995).

We note that this stance contrasts with what Cobb and Hodge and Engle and Conant may qualify as student engagement. More specifically, because both studies assess student engagement as participants' alignment to specific (though negotiated) norms and values, student-initiated "detours" might be construed as events of non-engagement. We contend, however, that occasional misalignments are unavoidable and reflect the natural complexity of classrooms. Indeed, our analysis will show that when we attend to the details of students' actions, we are almost guaranteed to see them going in one or more directions, each of which aligns to different degrees with the goals and norms sanctioned by the community.

1.3. *A Summary and Plan for the Paper*

In what follows, we begin by describing the research context within which this work was carried out. In particular, we introduce many of the details of the scientific image processing activities and host computational environment, as well as the larger classroom contexts of which computer-based activities were a part. This will give the reader a sense for the large dataset making up the raw data for the study.

Based on these raw data we then present three vignettes, each of which containing a number of episodes in which students appear to be engaged. In line with the definition above, we identify student engagement by attending to their actions (e.g., the effort they put in their work) and affective responses (e.g., the pride they display in their creations). These criteria apply to students' work on both proposed and self-initiated activities.

Next, we present a first analytical pass through the data, considering in detail the actions of students during engagement episodes. Relevant questions are: What exactly are students doing? What is the object of their actions? How do their actions relate to their behavior in previous computer-based activities and indeed across the course? What is the relationship between students' self-initiated and framed activities?

Out of this analysis emerges a list of five key phenomena characterizing students' behavior in self-guided, self-motivated engagement. These phenomenological elements are then synthesized into a "narrative" that explains how the phenomenological elements unfold in action. Specifically, as mentioned above, we identify students' personal excursions into parallel and/or related activities as a mechanism through which students tailor framed activities to their personal agendas.

We close by considering the factors that afford and support students' personal excursions, and present conclusions and avenues for future work.

2. RESEARCH CONTEXT

In the summers of 1997 and 1998, the Berkeley Boxer research group ran a course named "The Symbols of Science." The courses lasted six weeks and met twice a week for three hours. A typical day was divided into three segments of 50 minutes, with 15-minute breaks between segments. At the beginning of the course, roughly two thirds of a day's work was spent in the classroom and the remaining third was reserved for computer lab activities. Towards the end of the course this "equation" was inverted and lab activities consumed most of students' time.

The Symbols of Science were administered as part of the Berkeley Academic Talented Development Program (ATDP), a program intended to introduce talented students, grades 7 to 11, to topics in the sciences, arts, and humanities. As such, in the two editions of our course we had a number of good students, but a large majority could be considered average.[1] The student population represented a fair mix of gender and ethnicity, with a total of 10 female and 9 male students. Of this total, 5 were African American, 4 were Asian, 6 were Caucasian, and 4 were Hispanic.

The subject matter of the courses was representational design. More to the point, we wanted students to explore a topic that is at the center of mathematical and scientific practices – creating, refining, and using diverse representational forms (Janvier, 1987; Lynch and Woolgar, 1990; Greeno and Hall, 1997). Consonant with this idea, in a typical activity, students worked with crayons and paper to design a representation of a given phenomenon (e.g., motion patterns or terrain). In general, several cycles of design were enacted and each cycle was followed by whole-class discussions on the relative merits of the pool of representations. A full description of students' works in our ATDP courses, as well as reports on the larger context of this research endeavor, can be found in diSessa et al. (1991), Sherin (1997, 2000), Madanes (1997), Azevedo (1998, 2000), Granados (2000), diSessa and Sherin (2000) and diSessa (2002).

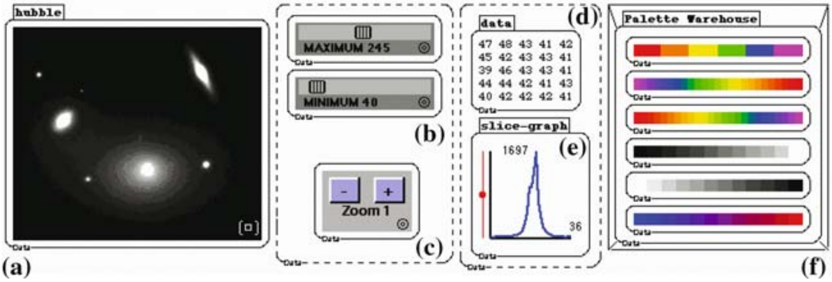
In the lab, students worked (individually or in small groups) on a variety of computer-based activities, the bulk of which focused on scientific image processing. The use of scientific visualization software as a target of instruction is consistent with the core goals of the course – i.e., scientific visualization technology is prototypically representational in the sense that it presents a visual display as a surrogate for data (Friedman and diSessa, 1999). Thus, lab activities provided a space for continued investigation of problems in representational design, while broadening the scope and domain of applicability of such investigations.

All classroom and lab activities were videotaped. Classroom activities were captured by two cameras, whereas lab activities were captured by a camera pointed at a focal group throughout the courses' length. Additional data include students' pre- and post-tests, field notes taken by researchers, personal notes (taken after the fact, but usually on the same day), activity files saved by students on lab computers, and a wealth of artifacts that students produced during paper-and-pencil activities.[2]

2.1. *The Image Processing Environment*

The scientific image processing environment was designed to highlight the representational character of images captured in some way and displayed on computer screens. For a better grasp of this point, consider the image of stars and galaxies taken by the Hubble telescope and displayed in our system (Figure 1). The image itself (Figure 1a) is a representation; each pixel in the image corresponds to a data value whose color is determined through a palette mapping.

Note that this description of the technology makes salient three core aspects of the underlying representational model: data values, a mapping, and a resulting image. Accordingly, the tools (Figure 1) provided in the activities operate on different parts of the representational model, allowing one to inspect or alter aspects of the model. Each of these tools performs a single, well-defined function. The *minimum* and *maximum* slider controls (MIN–MAX, b) allow



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47 48 43 41 42
45 42 43 43 41
39 46 43 43 41
44 44 42 41 43
40 42 42 42 41
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Figure 1. Set of image processing tools provided in the scientific image processing activities: (a) image of galaxies and stars; (b) the min–max controls; (c) the zoom control; (d) light intensity data values underneath the data peeker; (e) graph showing light intensity values of a cross-section of the top right-hand galaxy; (f) student-built palettes for image rendering.

changing the color mapping function through the adjustment of the outermost values in the mapping interval: Pixels with a data value equal to or less than the set MIN value (40, in the figure) are displayed in the lowermost color of the current palette, whereas pixels with data values equal to or greater than the set MAX value (245, in the figure) are displayed in uppermost color of the palette. Pixels with data value between the minimum and maximum settings are displayed in palette colors selected through linear interpolation. In the Hubble image, darker regions correspond to low data values (i.e., low light intensities) and brighter regions correspond to data values equal to, or greater than 245 (the MAX value).

The *zoom* control (c) changes the physical size of the image, enlarging or reducing it, but leaving the underlying data untouched. The *slice-graph* box (e) displays the sequence of data values of a linear ‘‘slice’’ drawn over the image. To draw such a line, one simply clicks and drags the mouse over the desired segment of the image. In Figure 1, the slice graph shows the light intensity values of a cross-section of the top right-hand galaxy.

The *data-peeker* (the bracketed square-shaped object in the lower right corner of the image) lets one inspect the data values underneath a rectangular portion of the image. These values are displayed in the array of numbers in the *data* box (d), which is continuously updated as the data-peeker is dragged around.

Finally, the *Palette Warehouse* (f) box contains a number of color and black-and-white palettes one may use to render the image. To render the image with a new palette, one clicks on the desired palette, drags the mouse to the image, and then releases the mouse button. As we will see next, palettes appearing in the Palette Warehouse are user-defined.

2.2. *The Palette Making Tool*

The Palette Making Tool, or PMT (Figure 2), is one among a few tools we designed to support students' work on a variety of image processing activities.

The rationale for the PMT design meshed considerations of students' prior knowledge (as gathered in formative studies), the instructional strategy of teaching image processing as a representational technology, and a hypothesis regarding factors that influence student engagement. As we have noted, palettes occupy a prominent role in the 3-prong representational model of image processing. At the same time, pre-implementation studies showed that students are very knowledgeable about using colors as representational devices (Azevedo, 1998; Friedman, 1998), and that color coding representational displays is an activity that occurs spontaneously to students (Azevedo, 2000). Furthermore, following our own work (diSessa et al., 1991) and that of others (e.g., Csikzentmihalyi, 1988), we hypothesized that knowledge and competence (broadly conceived) underlies self-directed engagement. As an initial design choice, therefore, the PMT was made to figure centrally in many of our scientific visualization activities. We will return to these points later in the paper; for the moment, let us describe briefly the main features of the tool.

The PMT is divided into two main modules, one for making colors and the other for constructing palettes. In the context of image

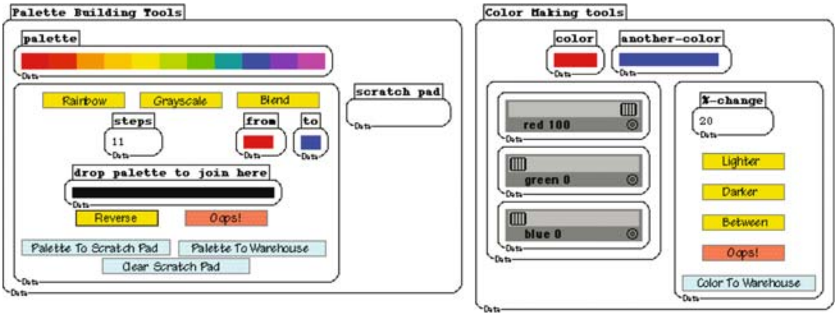

Figure 2. The palette making tool.

processing activities, the creation of palettes often starts with considerations of what the image depicts and what colors would best fit the context. For example, when the data represent altitude over a surface, students might choose to create a palette with tones of green and brown. This seemingly simple activity affords students an opportunity to apply their rich knowledge of representational conventions and clarity (Azevedo, 2000).

Once students decide on what colors should make up a palette, they manipulate the RGB sliders until they obtain a desired color. These colors can then be dragged to the *from* or *to* boxes in the palette building module. As the names suggest, these define the outer limits of the palette one wishes to create. After defining these limits, one can then just click the *Blend* button to create a palette with *steps* color elements interpolated between the *from* and *to* colors. Buttons are also provided so that one can easily create standard, pre-defined *Rainbow* and *Grayscale* palettes, or *Reverse* the color array of the currently displayed palette.

Finally, colors and palettes can be saved in their respective *Warehouses* and later accessed from within any activity (Figure 1, item *f*). As we will see, warehouses allow students to build their own preferences into the tool and to carry these preferences into activities of their own choice.

2.3. *Boxer*

Our computer-based tools and activities are implemented using the Boxer computational medium (diSessa et al., 1992). Boxer is an environment targeted at the K-12 population (students, teachers and curriculum developers) that integrates text and hypertext processing, a programming language (including a superset of LOGO), and dynamic and interactive graphics.

The basic organizational unit in Boxer is the box, which may contain text, programs, or graphic elements. Boxes may contain other boxes, forming a user-controlled hierarchy that can be used to organize documents. In Figure 1, for instance, the *Hubble* box is a graphics box containing an image and a user-controlled graphic object (i.e., the data-peeker), whereas the *data* box is a text box filled with an array of numbers.

Boxes may have multiple presentation modes, which can be accessed by “flipping” the box. To use an example pertinent to the image processing environment, flipping any of the palettes in the *Palette Warehouse* reveals a sequence of individual color elements. Likewise, flipping individual color elements reveals the red–green–blue values that make up a color.

All objects in the Boxer system, and indeed the system itself, are open to user inspection, modification, and extension. Direct editing and programming are the main means of modifying, controlling and extending the behavior of objects, and students often rely on those means to carry out their projects.

2.4. *Image Processing Activities*

Activities making up the full scientific image processing curriculum are described in more detail in Friedman and diSessa (1999). To give the reader an idea for what kinds of tasks appear in the activities, here we describe a single activity, one to which we will return throughout the paper.

2.4.1. *Beauty*

In Beauty, students investigate scientific visualization concepts using a "terrain" they know quite well: Their own faces. Students' faces are first captured with a digital camera, then imported as data values into Boxer's image processing-ready format.

The use of students' faces as an object of investigation fits a twofold rationale. As stated previously, from the point of view of student engagement designing an activity that relies on familiar contexts is meant to evoke knowledge that might aid in supporting self-directed engagement. Similarly, from the perspective of learning, the same well-known context facilitates students' identification of, and reasoning about, complex image features. For instance, when dealing with images of celestial bodies (say, the moon), it is common for students to interpret light image areas as representing peaks and dark spots of the image as representing craters or lower altitude terrain (Friedman, 1996). In contrast, while working with images of their faces, students can more easily see the relationship between light intensity (as captured by the camera) and features of their face, and thus begin to learn how to critically assess their initial interpretations of the displays. For these reasons, in terms of our image processing curriculum, Beauty is the first encounter students have with image processing *per se*.

The Beauty activity is structured as a series of tasks, each of which requires the use of one or more procedures for its solution. We use the term *activity-as-framed* to refer to an activity's set of tasks and their instructional goals, as well as roughly the expected means through which students might come to achieve these goals.

As a first task, students are asked to generate hypotheses about why the image gets grainy as one zooms into it, and the progression of the activity provides many clues as to why this might be the case. Next, students are introduced to the data-peeker tool and asked to deploy it as a means of checking the predictions generated in the first task item. The succeeding task requires students to use the slice tool to begin reasoning about how variations in image appearance over a line relate to data values. With the sequence of curriculum activities, students come to appreciate that data inspection tools (i.e., the data-peeker and slice tool) are differentially powerful and their use context- and goal-dependant.

The next task asks students to make their nostrils salient. To do so, some coordination between the use of MIN–MAX controls, slice tool and/or data-peeker, and palette making must be achieved. The finer the coordination and understanding of the underlying data, the better the results.

Finally, students face four challenges. In challenge 1, students are asked to color their hair green, whereas in challenge 2 they need to make their eyes blue. Challenge 3 requires students to turn the image into a photographic negative, and challenge 4 poses the difficult task of blurring the image.

3. THREE VIGNETTES

In this section, we present three vignettes taken from our ATDP courses. The vignettes set the context for the analyses that follow and also introduce some of data with which we will work. As the paper progresses, however, more data are provided that fill in details not presented here.

Ideally, our data presentation and analysis would rely on records of the lab focal group. Unfortunately, the relatively low quality of lab videos prevents us from doing so.[3] We thus follow students for whom we have relatively solid data. Any incompleteness in data records will be flagged in the narrative.

3.1. *Vignette 1: Contrast as a Powerful Representational Idea*

The *Moon* and *Hubble* activities were scheduled, in this sequence, for a one-hour period on the last week of classes. In both activities, students were asked to reason about difficult problems, such as comparing the relative heights of crater walls on the Moon and distinguishing between stars and galaxies in an image taken by the Hubble telescope.

While working on the *Moon* activity, Dean (8th grade, ATDP ’97) could be seen exploring and tinkering with diverse elements of the interface. This somewhat playful style of experimentation seemed to characterize Dean’s overall approach to that course’s classroom and lab activities, more so than Peter (7th grade), Dean’s partner in the lab.[4]

Although tinkering and “free-form” exploration appears to be an apt description of Dean’s overall mode of investigation, he did not try out things in a random fashion.[5] Rather, Dean showed aesthetic concerns that strongly reflected the artistic inclinations he displayed throughout the course. When describing his approach to representing a model landscape with paper and pencil, for example, Dean remarked:[6]

6/27/1997		
46:41	Dean	See my ((*art*)) teacher taught me about this once in my class and ... I figured I’d try it... see what you do is you don’t look at your paper... and you try and draw what you’re looking at.
	Teacher	Uh huh//
	Dean	//and see... so here’s that one big mound ((*points to his representation*)) and the... stuff in front of it it’s there ((*points to his representation and an object obscuring another*)) ... and here’s the little... other... there’s the other mound and... there’s the stuff behind this mound.

Finding “interesting” color combinations for a palette appeared to be a particularly motivating activity for both Dean and Peter. In any given software-based activity, they could be seen creating and refining a number of palettes, which they often saved (file: Dean_Beauty; file: Dean_Geezer). Figure 3b shows the palettes that Dean and Peter saved during both the *Moon* and *Hubble* activities.

Perhaps as a natural extension to the insistent palette creation work they carried out since the early moments of that day’s activities, when working in *Hubble* Dean and Peter decided to introduce in a palette a color that strongly contrasted with its neighbors. Because at that time the Palette Making Tool did not support arbitrary, user-controlled interspersing of colors, Dean and Peter had to work around tool limitations in order to achieve the desired effect. Because the students accomplished their goal on their own, they must have

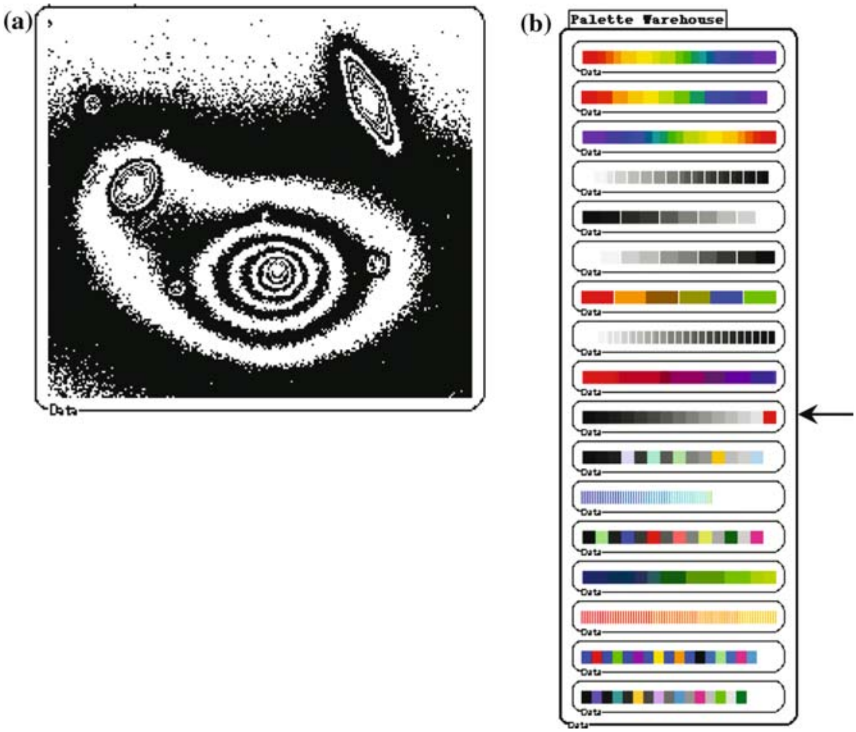

Figure 3. (a) Hubble image rendered with the zebra palette; (b) palettes saved with Dean and Peter’s Hubble file. The arrow points to the first “special” palette those students created that day.

spent some time "poking around" until they finally figured out how to flip boxes and edit individual palette colors.

Having succeeded in creating the unusual palette (see arrow, Figure 3b), Dean and Peter rendered the galaxy-and-stars image that was the object of study (file: Dean_Hubble). Noticing that the procedure resulted in a strong feature highlighting effect, they started anew, laboriously arraying on a palette a number of selected color elements, each of which contrasted sharply with its neighbor. Eventually, the students created what we came to call the *zebra palette* – a sequence of interpolated, highly contrasting color elements. Zebra palettes have the property of highlighting boundaries between ranges of data values in an image (Figure 3a). In conventional scientific terms, a zebra palette creates contour regions.[7]

Notice that the particular zebra palette used in rendering the image in Figure 4a does *not* appear in the group's Palette Warehouse (4b). This is evidence that Dean and Peter created more palettes than they cared to save.

3.2. *Vignette 2: Neat Illusions*

Despite the course's focus on representational design, as a final project Cathy and Carl (9th grade, ATDP '98) investigated illusions formed by certain representational displays. Their choice was moti-

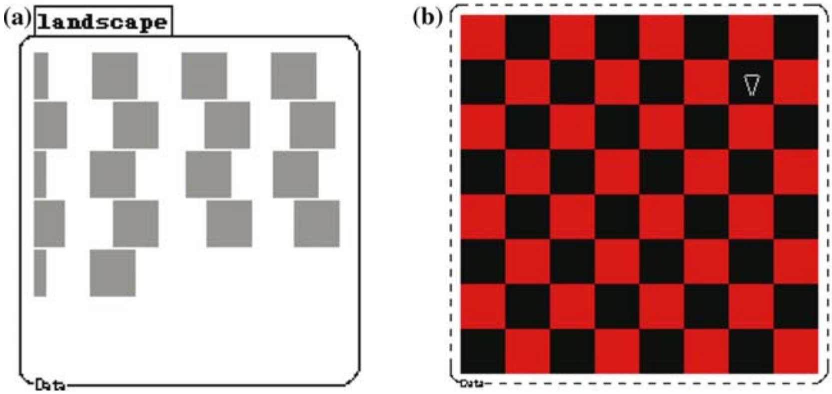

Figure 4. (a) The "café wall" illusion, as programmed by Carl and Cathy on the fifth week of classes. Squares in the same row are aligned, though perceptually they appear tilted; (b) checkerboard graphics (file: Checkerboard) programmed collaboratively by Cathy, Carl and Beth on the first week of classes. Each student chose to save his/her own Checkerboard file.

vated both by a suggestion we had made and by Carl's interest in perceptual illusions.

With help from the teacher, Cathy and Carl approached the problem by consulting a book on the psychology of perception. From the book, they picked an illusion commonly known as "the café wall illusion" (Figure 4a). To simulate the illusion, the students requested that we made some additions to our Landscape Construction Kit (LCK; Obs_7/13/98, pp. 1–2). Briefly, the LCK allows one to edit graphic displays, much in the way drawing programs work. In the context of the image processing environment, however, the editing actions in the LCK result in changes to the underlying data, which are meant to represent altitude information.

We carried out the modifications that Carl and Cathy requested and from that point on they began their work, first by editing the illusion display. Then, they varied different parameters of the illusion. For instance, they wondered whether the illusion effect is observable in color renderings of the image, as well as in black and white versions of it. As their investigation progressed, however, Carl and Cathy decided that they needed to repeatedly edit multiple parameters of the display, starting anew each time. The new requirements led students to judge that the LCK adaptations we had implemented were not up to the task; briefly, using the tool entailed a cumbersome and slow editing procedure. As Carl put it during a whole-class project progress assessment held during the first class of the last week of the course:

7/20/98		
24:51	Teacher	So what variables have you changed so far?
	Carl	We're... we can... we... there's lots of things we'd like to try but Boxer's ((*LCK*)) like uh:: ... is hard to manipulate so it takes a long time to... change it. That's why we have a small grid as opposed to a big... one.

So Carl implemented his own tool, in his spare time, using a copy of Boxer that he installed in his home computer. Carl's program used pieces of a simple square-stamping procedure (Figure 4b) that he had previously written, as a "side-task" he carried out during the very first computer-based activity in that course. On that occasion, Carl, Cathy, and Beth (the protagonist in the next vignette) were working together, and collaboratively they explored some basic graphics functions of Boxer (Obs_6/15/98, p. 6; Obs_6/22/98, p. 3).

With the new tool in hand, Cathy and Carl were again ready to proceed. In a more or less systematic way, they resumed experimenting with various attributes of the image, saving printed versions of each of their experiments. During project presentation, they developed a convincing explanation regarding the psychological and physiological basis of the illusion, and remarked on some of its aspects that they could not understand (video: 7/23/98).

3.3. *Vignette 3: Extending the Existing Tool Set*

Beth was a ninth grader when she attended the 1998 edition of our summer course. From the very beginning Beth's interest in design and programming was evident. She excelled in most activities and frequently engaged in self-directed forays (programming or otherwise) during and after completing the assigned tasks (see vignette 2).

An interesting episode took place when Beth was working on challenge 1 of the final tasks in Beauty. Having achieved the desired effect (i.e., coloring the hair area green), Beth had the idea of singling out the smile in the image. Beth spent quite some time attempting to obtain the intended result, creating a number of palettes in the process and using MIN–MAX controls extensively. Once satisfied, Beth called the teacher and declared she had created the "Cheshire Cat" (Figure 5). Beth then went on to describe how she had achieved her goal and, showing some frustration, she engaged in an explanation as to why it was not possible to completely obscure her hair and to single out her smile fully. Beth's pursuit apparently consumed a good chunk of her attention, as she did not make it past the second challenge in Beauty (file: Beth_Beauty). As an indication of the significance the "Cat work" had taken for her, Beth chose to save a separate file containing only the final rendered image and palettes she created in the process (file: Beth_Cat, Figure 5).

Given Beth's history in the course, we were not surprised when she decided to pursue an extremely technical final project. As she articulated more or less during her project presentation, Beth had been puzzled by what she considered to be gaps in the functionality of some image processing tools:

7/20/98		
3:51	Beth	((*Beth is opening two boxes on the screen*)) These are ((*inaudible*)) x and y ((*inaudible*))//
	Teacher	Wait a minute… uh:: what what's the problem you're trying to solve? Can you tells us a little bit//
	Beth	// I'm just trying to do some helpful things with min and max… yeah… and uh:://
	Karla	// What?
	Beth	I don't really have a problem I'm trying to solve I just wrote some helpful programs with min and max… there were I mean I thought about it and I thought you know what things take too long to do or whatever ((*inaudible*)) what tools I could do to help with that ((*inaudible, 1s*)) and that's what I decided ((*inaudible*)) seemed like the most fun… if for no other appropriate reason.
	Teacher	Uh huh
	Beth	((*pointing with the mouse*)) and these are ports and they'll help you see things//
	Researcher	// So these are general tools for people working with min and max is… for palettes or//
	Beth	// Yeah anything with ((*inaudible*)) palettes and different colors.

In a nutshell, having used the MIN–MAX controls countless times to adjust the displayed images Beth expected that mouse-clicks on the image would somehow rearrange the MIN–MAX controls. But upon trying to mouse-click the image a few times, Beth concluded that her assumption was not true. As it turns out, mouse-clicks on the image were not assigned any function because the operation has no straightforward meaning in the context of image processing.

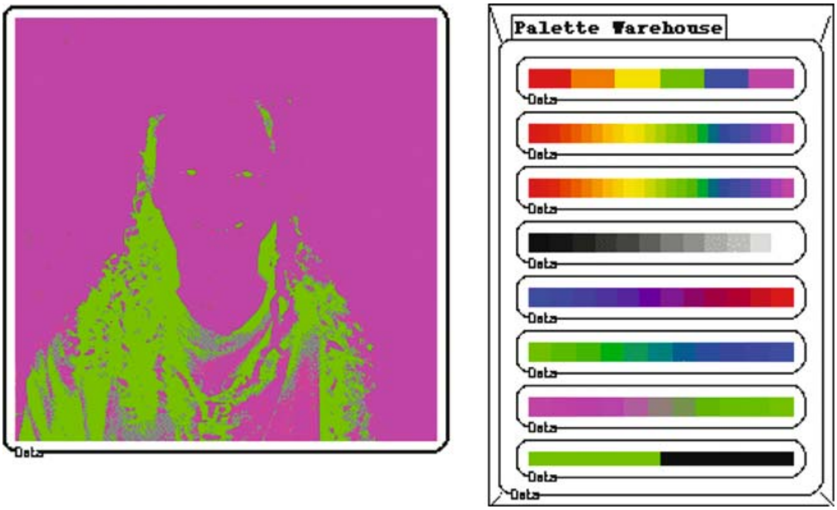

Figure 5. Beth's version of the "Cheshire Cat" and some palettes she built and saved during the activity.

When time came for students to choose and work on final projects, Beth set out to program the rearranging function (which she called "color zooming") that she had imagined earlier in the course. Beth's tool – which she implemented from scratch with some help from a researcher – attends to mouse-clicks on the image and reads off the numerical value of the pixel on which the mouse was clicked. It then computes what color that particular value maps to and the range of values that such a color represents. Finally, it sets the minimum and maximum values (and slider controls) to the upper and lower limits of that range, somewhat reversing the mode of operation of these controls.[8] This procedure "tunes" the new mapping function to a specified range of values, effectively "zooming" onto these values in "color space."

4. WHAT DO THE VIGNETTES TELL US ABOUT ENGAGEMENT? A SECOND PASS AT THE DATA

Having presented episodes of self-motivated, self-directed, relatively extended student engagement, we can begin to paint a more textured picture of the dynamics of open-ended classroom activities in which such an engagement mode is observed. Towards this goal, we survey the vignettes in search of key phenomenological aspects characterizing the kind of engagement we seek to explain.

4.1. *(i) Student-initiated Activities*

Perhaps the most compelling, common attribute of the vignettes is the high degree of student initiative each vignette portrays. By student initiative we mean that students were able to set new goals for exploration and, at least initially, to formulate actions roughly required in pursuing these explorations. We refer to activities that students devise on their own as *student-initiated.*

Student-initiated activities can be viewed as falling along a continuum of time duration. In this manner, the final projects appearing in vignettes 2 and 3 illustrate student-initiated activities of very long-term duration, whereas Dean and Peter's creation of zebra palettes (vignette 1) lies somewhere between short- and long-term pursuits.

Also, notice that multiple instances of student-initiated activities are implicated in vignettes 2 and 3, all of which comprised events of much shorter duration. In vignette 2, part of the motivation for Carl's final project implementation resides in his early, self-directed forays into programming simple graphic displays. In vignette 3, Beth's final project results from questions and explorations that she independently formulated in earlier software-based activities in that course, possibly including those in the Beauty activity.

The ability to choose one's own exploration paths and the freedom to formulate one's own actions are commonly termed self-determination. Self-determination is thought to be an important component behind student engagement with school work (Deci, 1992).[9] More generally, Csikzentmihalyi (1988) has shown that one's ability to control the outcomes of an activity plays an important role in motivating an individual to pursue varied types of activities, from chess playing to rock climbing. As it appears here, student-initiated activities is the vehicle for students' exerting control over the given software-based activities and, as we will see, it plays an important role in explaining the engagement we observed.

4.2. *(ii) Autonomous Performances*

A common goal of teachers and educational researchers is to support students as autonomous learners (see, for example, Linn and Hsi, 2000, pp. 181–212). At least sometimes we would like students to take over the learning process, generating their own questions and managing the progress of their investigations in a reasonably competent manner.

Our description of student-initiated activities above already highlights some degree of autonomy in students' pursuits. But the process of pursuing self-directed, self-sustained activities involves more than devising end-goals and plausible exploration topics. One needs, for instance, to formulate alternative solutions, to recover from problems and misguided steps, and/or to recognize potentially complicated or time-consuming investigation paths. Fundamentally, to initiate and continuously pursue an activity, one needs to know something that bears (however tenuously) on the subject matter of the task.

Overall, we believe our vignettes illustrate a high degree of autonomy in these students' performances. Dean and Peter's creation of zebra palettes (vignette 1), Carl's decision to implement his own square-stamping tool (vignette 2), and Beth's work on the Cheshire Cat and successful completion of her color-zooming function (vignette 3) all stand as evidence of students' ability to conduct their own pursuits in a relatively successful fashion.

In spite of the high degree of student autonomy we observed, we should point out that students' investigations did not always proceed flawlessly. On the contrary, students sometimes hit dead-ends or embarked on seemingly unfruitful pursuits. Furthermore, it is important to mention that students did not know all they needed to accomplish their goals. For example, Carl and Cathy probably did not know all that was entailed in implementing an alternative to the tool they were provided (vignette 2). However, in light of their previous experience with graphics-handling routines, Carl and Cathy knew that the tool they envisioned would provide a better means to reach the goals of their investigation. More obviously, given the similarity between the illusion and checkerboard displays, Carl and Cathy must have known that adapting the checkerboad program (or even programming it from scratch) was a goal easy enough to accomplish and that it would not consume an inordinate amount of time.

4.3. *(iii) Students were not always On-task*

As we have defined it here, student-initiated activities often result in explorations that may be considered off-task. Traditionally, off-task work is said to consist of activities whose goals are parallel, marginal or unrelated to the goals of the activity-as-framed. In contrast, on-task work can be defined as that which fully matches the conceptual and pragmatic goals of the activity-as-framed.

To elaborate on points made in the introduction, we take on- and off-task work to be a matter of degree and kind. In this manner, we are bound to observe some student-initiated activities that constitute "detours" from designed goals, but which still somehow relate to these goals and/or the domain subject; others might be clearly unrelated to the domain under consideration. Additionally, students may be off-task in several distinct ways, such as focusing attention on particular tasks in the activity-as-framed in detriment of others or avoiding working on more thorny issues that appear in that activity.

To exemplify these points, let us first return to vignette 1. Recall that, as part of the Hubble activity, students were to use palettes as a means of reasoning about particular aspects of the task. While working on the activity, however, Dean's goal became one of creating palettes with very particular color patterns. In pursuing such a goal, Dean's group engaged in an activity (i.e., palette-making for the sake of studying features of the image) that still bore some relation to the tasks in the activity-as-framed. However, Dean and Peter's goals were apparently mostly aesthetic and we do not know the extent to which their pursuits connected with the many learning objectives of the activity. Furthermore, because Dean and Peter did not finish all tasks in Hubble (file: Dean_Hubble), these students appear to have dedicated a great deal of attention to palette-making, perhaps to the detriment of other tasks in that activity.[10]

Similar points may be made with regard to Beth's work on the Cheshire Cat (vignette 3). Beth's pursuit was not expected or proposed in Beauty, but it is very much within the general frame of the activity and thus may be considered nearly on-task. Conversely, because Beth's endeavor prevented her from fully considering the remaining challenges in the activity-as-framed, some may contend that she was at least partially off-task.

Lastly, and perhaps more significantly, Cathy and Carl's final project (vignette 2) may be termed nearly off-task because the nature of their explorations (i.e., perceptual illusions) does not relate in any straightforward manner to the goals of the course (i.e., representational design).

Regardless of how much students' deviate from assigned goals, our vignettes seem to suggest that occasional off-task work is an unavoidable "by-product" of the particular mode of student engagement we have observed. Lest we think this phenomenon has mostly deleterious consequences, we now provide evidence that students' self-initiated endeavors have important, positive consequences for their overall learning.

4.4. *(iv) Collecting Resources that Bear on Local and Future Action*

All three vignettes contain evidence that student-initiated activities resulted in students collecting *resources* that were useful locally (i.e., in the context of the current activity) or in follow-up activities (i.e., those making up the full scientific visualization unit). These resources may be of various types, such as conceptual (e.g., developing a deep understanding of some aspect of the image processing representational model), pragmatic (e.g., acquiring facility with the use of system or image processing tools), or simply question-generating.

As an example, we turn to vignette 1 once more. We saw that Dean and Peter wandered off-task while pursuing the idea of zebra-palettes. Although we cannot precisely pinpoint what Dean and Peter learned in that particular episode, we speculate that they developed at least some fluency with practical aspects of Boxer's operation and structure – for instance, general ways of working with the interface (e.g., flipping boxes), the way palettes are represented as sequences of individual colors, and the way colors are represented as RGB values. Such learning would be, at a minimum, a resource of pragmatic consequences for all subsequent software-based activities, and perhaps underlie the learning of more conceptually-oriented material.[11]

Significantly, though perhaps accidentally, Dean and Peter's creations were later useful in addressing at least one task within the context of *Moon* and *Hubble*. As evidence, roughly midway through the *Moon* and *Hubble* activity sequence a researcher asked Dean and Peter how they had created their special palettes. Dean's response suggests that he was busy at some counting task.

7/7/97		
37:01	Teacher	((inaudible)) you're sort of just dropped so::me additional colors in there? ((inaudible))//
	Dean:	// wait wait one two three four... six EIGHT ((inaudible))

What could Dean be counting? The answer is to be found in an episode that took place later in the activities, a few minutes before students were asked to finish their lab work and reconvene in the classroom. In this episode, the teacher is querying the focal group about the total number of objects in the Hubble image, which was one of the tasks in that activity.

7/7/1997

57:24	Teacher	Is that a ((*1s*))((*points to the screen*)) is that an object?
	Angela	It looks like one
57:45	Angela	It's red ((*inaudible*))//
	Tamara	// that's eight objects ((*puts indicator finger on the star and galaxies image*))
	Teacher	I guess you're RIGHT//
	Dean	// yeah there's eight objects on that ((*1s*)) I did it with a different palette

Having worked through the issue, Dean jumps into the conversation to his side and, in a tone of voice that denotes certainty, he confirms the focal group's conclusions. Dean's certainty is somewhat warranted – a large enough zebra palette makes it easy to resolve the number of celestial objects in the image because of the sharp contrast it provides between data value boundaries.

Vignette 2 also exemplifies how students' self-initiated activities resulted in resources that later fed back into course activities. Although not exactly in line with the activity within which they were carried out, Carl's early experiments with graphics functions paved the way for his later implementation of a simple tool that was crucial to his group's final project work. In particular, his square-stamping procedure, produced in the initial stages of the course, could be used as part of that project. More subtly, but importantly, those very same experiments may have given Carl a better notion of how much effort he would have to put into adapting that initial program to his project's needs.

Finally, Beth's (vignette 3) repeated, independent attempts at uncovering the innards of the imaging technology halfway through the course resulted in her eventual formulation of a question that later drove her final project investigation. Beth's question constituted a resource not just because it motivated a final project, but also because it may have guided her attention and learning efforts in subsequent activities.

4.5. *(v) Students' Actions were Sometimes Tentative and/or Exploratory*

We have highlighted that students were capable of formulating and pursuing a range of complex goals and activity paths. However, it should be noted that student-initiated activities illustrated in the vignettes (as well as in events preceding or implicit in the vignettes) were frequently "tentative and/or exploratory." By tentative and/or exploratory we mean two things.

First, student-initiated activities, as we have observed them, appear to have a fluid goal structure. More specifically, goals that motivate students' self-initiated endeavors at first may not be persistent, so that such goals are formed and abandoned depending on how successful or interesting (for students) the results of current interactions are. When goals are not persistent, students may seem to change directions with relative frequency. As an example we will consider in more detail, while attempting to create zebra palettes (vignette 1) Dean and Peter did not seem to stick strictly to the goal of making special palettes. By the end of that episode, they had engaged in many simultaneous activities, some of which got dropped along the way.

Second, individuals' goals themselves may not be initially clear or fully articulated. That is, students may start out with ideas that seem interesting, achievable, or that satisfy some criteria of personal relevance. But upon further investigation these ideas might prove to be trivial, boring, or too complex to pursue (cf. Csikzentmihalyi, 1988). Initial goals might then go through revision, a fact that characterizes their tentative character. In the next section, we will see that this phenomenon reflects the interest-based character of students' self-initiated investigations.

5. SYNTHESIZING THE PHENOMENOLOGY

The list of phenomenological elements in the previous section appears as a loosely coupled, though somewhat coherent set of items. In this section, we better show the interdependence of phenomenological elements by exploring how they unfold in action. As an aid to the reader, whenever appropriate we index the narrative to the phenomenological elements laid out in the previous section. For quick referencing, Table I lists phenomenological elements and respective short descriptions.

5.1. *Personal Excursions*

Personal excursions are episodes when students "bend" or leave the activity-as-framed in order to pursue personal agendas and interests. In essence, "bending" or leaving a proposed activity amounts to initiating a new activity that relates, to a greater or lesser extent, to the activity-as-framed, but which does not fully align with its framed goals.

Personal excursions may last for more or less time, but the general trend is for students to resume work on the activity-as-framed, either upon completion of their self-initiated pursuits or sporadically, as part of their conscious effort to keep up with the activity-as-framed. As we will see, yet other factors might cause students to veer back to the activity-as-framed. The point to observe, though, is the pattern of investigation that students follow, its dependence on students' longstanding and emergent goals, and the relationship between those goals and the goals of the activity-as-framed.

To better grasp this idea, let us consider the dynamics of personal excursions, shown schematically in Figure 6. The figure provides a simplified view of the activity dynamics typical of the self-directed, self-motivated engagement portrayed in our vignettes. In the figure, the large gray arrow represents a hypothetical investigation path covering the conceptual and pragmatic goals of the activity-as-framed. The thickness of the arrow is intended to symbolize that

TABLE I

Summary of phenomenological elements common to the vignettes

Phenomenology	Short description
i	Student-initiated activities
ii	Autonomous performances
iii	Students are not always on-task
iv	Collecting resources for local and/or future actions
v	Students' actions are sometimes tentative and/or exploratory

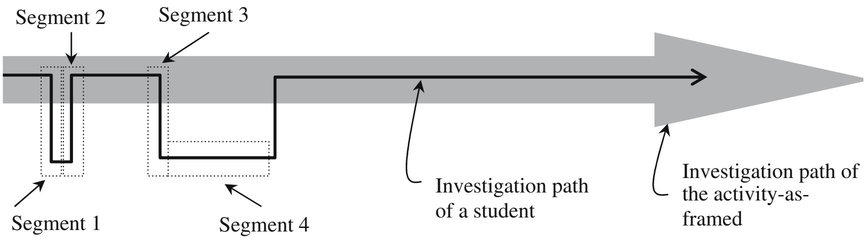

Figure 6. A schema of the dynamics of personal excursions.

several paths – each composed of a number of reasoning strategies, procedural approaches, and so forth – can possibly satisfy the goals of the activity-as-framed.

The black, winding line represents a hypothetical activity path of a student while working on a given proposed activity. Starting on the left side of the figure, we can imagine that the student begins working on the activity-as-framed attempting to advance through its goals. For instance, in the early moments of the *Moon* activity, Dean and Peter (vignette 1) appear to be using one of the given tools (either the data-peeker or slice tool) to solve a proposed task.

7/7/1997

8:24	Dean	((*paraphrasing the first task in the Moon activity*)) Crater near the bottom… which one has a higher wall?
8:53	Dean	((*inaudible*)) Upper right? O::kay.
9:12	Dean	HOLLY shoot ((*inaudible, 1s*)) one seventy five.
9:20	Peter	Oh, THAT'S RED, THAT'S RED.
9:30	Peter	Cause we're looking for the highest point ((*inaudible*)).

As they progressed in the activity, however, Dean had the idea of making non-standard palettes. As explained in vignette 1, Dean's idea is consistent with the frantic palette work his group carried out since the beginning of that day's activities. Dean and Peter then went on to pursue this idea, taking an activity path that appeared to lead to their goals (phenomenology *i*).

In doing so, however, Dean and Peter started an activity that related to some of the tasks in the activity-as-framed, but which did not fully align with the goals of that activity (phenomenology *iii*).[12]

This event is shown as a "detour" from the canonical activity path (segment 1, Figure 6) and it constitutes the group's first personal excursion in the context of this hypothetical activity sequence.

Now suppose that, at first, Dean and Peter's self-initiated pursuit bears little fruits (from their perspective). For instance, they might have thought they could implement "special palettes" with existing functions in the Palette Making Tool. But upon realizing that was not possible, they decided to drop the idea and resumed work on the activity-as-framed (segment 2). This would illustrate students' ability to recognize a potentially impossible or lengthy project, as explained in phenomenology (*ii*).

Incidentally, assuming this initial excursion is short-lived, it also exemplifies phenomenology (*v*). As the reader will recall, our observations revealed that students' emerging goals are sometimes only partially formulated. These goals and associated activities are abandoned if proved problematic, or if more promising ones – including returning to framed tasks – can be envisioned.

Whatever the reasons for abandoning their initial excursion might have been, we know that Dean and Peter eventually resumed work on the activity-as-framed; their successful completion of several tasks in the *Moon* and *Hubble* activities stand as evidence of this point.

Interested as Dean is in art-related activities, after working some more on the activity-as-framed he and Peter decided to give the original idea another try (segment 3), setting out on another personal excursion. This time, however, the students are determined in face of difficulties, and spend significantly more time on their pursuit than before (segment 4). Indeed, we know the group never finished some tasks in *Hubble* (file: Dean_Hubble), so one of their excursions likely consumed a good chunk of their time.

Dean and Peter's insistence finally paid off and, as described in vignette 1, they managed to insert a red color element in a gray-tone palette. The final rendered image, which they proudly[13] saved, produced a striking feature highlighting effect. In turn, this result seems to have sparked a renewed interest in the "special palette" activity and they proceeded in the same direction until they finished a large number of zebra-like palettes (Figure 3b).

Having achieved their goal, Dean and Peter returned once again to the activity-as-framed. But as suggested previously, other circumstances might have taken them back to the canonical path. The point is that students step out of the activity frame but eventually return to pursuing that activity's goals. Dean and Peter's work on zebra palettes clearly illustrates this point (vignette 1), as do Carl's early work on graphics functions (vignette 2) and, to some extent, Beth's pursuit of the Cheshire Cat (vignette 3).

5.2. *Local Excursions and Long-term Activity*

We interpret phenomenology (*iv*) as a consequence of students' personal excursions. More specifically, by virtue of their individual-relevant, interest-based nature, personal excursions are likely to result in students collecting resources that feed back into local and/or future, related activities.

Obviously, not every personal excursion will lead to students collecting resources of any kind. For example, a short-lived, failed attempt at initiating an activity may not result in the collection of any relevant resource. Still, given enough time and a large enough set of curricular activities, chances are that one's personal excursions will result in the accumulation of pragmatic, conceptual, and/or question-generating resources that are relevant in the larger, extended context of the curriculum.

Indeed, a fundamental methodological and analytical move to understanding the pedagogical relevance of students' local, self-initiated pursuits is to observe the extended history of their investigations, looking for moments in which the object (broadly construed) of an excursion recurs in subsequent events – an approach akin to that used by researchers in the cultural-historical tradition (e.g., Engeström, 1999). Within this perspective, what locally appears to be a simple detour or off-task work may later prove to be a fundamental piece of knowledge anchoring a student's investigation or his/her developing understanding of the subject matter under consideration.

5.3. *What do Personal Excursions Tell Us about Self-guided, Self-motivated Engagement?*

Looking across the vignettes, we see that personal excursions show a significant degree of variability and unpredictability along three dimensions – i.e., goals, timing, and resources garnered.

First, the object and goals of students' excursions vary widely among students. For example, while Dean and Beth may have had aesthetic goals in their respective pursuits, the means through which each student approached his/her goals differ markedly – the first required radically different palettes, whereas the second made coordinated use of standard palettes and MIN–MAX controls.

Second, the timing of personal excursions is difficult to predict and shows a great inter-subject variation. In retrospect, in light of Dean's strong artistic inclinations and playful overall attitude, it is not surprising that he engaged in non-standard palette making. But why that activity occurred only later, rather than earlier in the course is not known. It is feasible that Dean's idea of non-standard palettes took time to build up, but it could also have been sparked by the particular context of the *Hubble* activity. In contrast, Beth's Cheshire Cat excursion happened relatively earlier (i.e., the fourth week of classes) than Dean's work on zebra-palettes (i.e., the sixth week of classes).

Third and last, resources collected during excursions will manifest themselves in practically unpredictable ways. To illustrate this point, recall that Carl, Cathy, and Beth worked together at the very beginning of lab activities, on which occasion they explored the graphics capabilities of the system. Any resources garnered during these early explorations will be used in subsequent activities in a manner that is highly contingent upon the nature of such activities. Because those activities are crucially dependent upon students' developing goals and interests, we cannot fully determine what and how resources will be deployed.[14]

Overall, the unpredictable and variable character of personal excursions points to the multi-faceted and contingent nature of individuals' interests and goals. This observation has important implications for how we design classroom contexts that foster self-guided, self-motivated, relatively extended student pursuits. We return to this issue in the next major section of the paper.

5.4. *The Significance of Personal Excursions to Supporting Student Engagement*

From the arguments thus far, we can conclude that personal excursions affect engagement in two particular ways. To begin, personal excursions allow students to build connections between the local environment – including proposed learning goals and resources – and their personal agendas. We believe this to be a strong generator of energy for students, as well as a good way to personalize the learning experience.

In addition, personal excursions provide a mechanism through which students build competence so that more extended, coherent personal pursuits are possible and more likely to occur. Examples of this point can be seen in the way Beth's and Carl's earlier pursuits supported and fed back into their course projects.

6. WHAT MAKES PERSONAL EXCURSIONS POSSIBLE?

Given the arguments thus far, it behooves us to explain the factors that underlie one's ability to take personal excursions. In other words, what makes personal excursions possible?

Undoubtedly, there are myriad "pre-conditions" for this mode of work to take hold. For instance, the open-ended nature of the software-based activities – and indeed all activities in that course – can be said to encourage students' initiative and self-directness. Likewise, features of the classroom culture in which the aforementioned events took place must have supported extended inquiry and students' positive attitudes toward the course's material. Teacher interventions and encouragement likely constituted important factors in fostering and sustaining students' pursuits.

As important as these factors are to fostering student engagement, they do not operate at a level of specificity that allows for a satisfactory explanation of the dynamic patterns characteristic of personal excursions. For example, one can easily imagine scenarios in which the above mentioned factors would be at work, but students were given resources (computational or otherwise) of a very different nature. This could conceivably alter students' ability to pursue and express their interests, thus changing patterns of engagement in a profound way.

In light of these observations, we select moments of self-guided, self-sustained interaction between students and computer-based activities as most significant events for explaining the factors underlying their ability to pursue the proposed activities and those they devise on their own. We single out students' *competence*, the proposed *activities*, the *time* students were given to work on such activities, and the nature of the *computational medium* as factors of highest importance.

6.1. *Competence*

There is no doubt that student competence played a crucial role in shaping their personal excursions. As prominently expressed in phenomenologies (*i*) and (*ii*), student competencies underlie their ability to engage in the various computer-based activities, as well as to initiate and to carry on their own pursuits.

That students were relatively competent to perform within the boundaries of the activity-as-framed, as well as in their self-initiated activities, is no coincidence. As described earlier, our activity designs were preceded by formative work whose attempt was to map out students' knowledge that could apply to the subject matter at hand. As much as possible, we wanted to identify knowledge that is relatively well developed so that activities that draw upon such knowledge were likely to support nearly self-sustained and fluid performance. Two particularly significant pools of knowledge uncovered in formative work were made to anchor parts of framed activities. First, we found that students have extensive knowledge of the uses of color as representational devices (Azevedo, 1998, 2000). Second, we discovered that students are quite adept at generating and refining interpretations of representational displays (Friedman, 1996).

The fact that competence has featured prominently in many treatments of engagement lends additional support to our arguments here. For instance, Newman et al. (1992) propose a model in which engagement is a function of individuals' need to express and develop competence. The authors do not provide an articulation as to how this intrinsic need for competence arises, but they suggest that successful expressions of competence foster continued involvement in classroom tasks. Authentic work (i.e., work that connects to students' real world concerns and provides them with a sense of ownership over the final products) and an environment that nurtures identification with school membership are the two venues they identify as key for the process of competence expression.

Studies from the socio-cultural tradition have also shown concern for students' competence, although not necessarily by this name. For example, Herrenkohl and Guerra (1998) see engagement as transformation of participation in activity structures that emulate those of disciplinary practices. Such participation structures, however, are well known to students and constitute ways through which students can more easily engage their competence (e.g., interactional, verbal, and so on).

Finally, Csikzentmihalyi (1988) suggests that engagement is maximized when a person's competence to perform in a task matches the challenges posed by the activity. Mismatches between competence and challenges yield less optimal engagement and even complete withdrawal from the activity. Csikzentmihalyi has applied his ideas in analyzing engagement in activities as diverse as mountain climbing and chess playing (Csikzentmihalyi and Csikzentmihalyi, 1988).

6.2. *Activities*

Activities provide the conduit through which students express their competence. From the point of view of personal excursions, designing activities in which students always find themselves in their "regime of competence" (diSessa, 2000) is crucial because it is only within competence that one can imagine new avenues for investigation. This seemingly trivial observation has important consequences for design. To consider some consequences, let us contrast our design approach to others'.

A contemporary, prevalent stance in science and mathematics teaching and learning has been to engage students in activities that resemble the practices of professionals (see, for example, Brown et al., 1989). As the argument goes, students should be given the tools of science and allowed to work on problems of real significance, perhaps including current scientific controversies and debates. In addition, students should participate in discourse practices that mimic those of practitioners and/or perform investigation procedures that match their professional counterparts.

We agree with the general form of this argument, in particular with the idea that science instruction should ease students' entry into the professional world. However, we believe that a strong allegiance to that stance may lead to activity designs that are not optimal from the perspective of engagement (diSessa, 1992). For example, from the point of view of students' competent performance in the domain of scientific image processing, interpreting images of the moon might be initially hard. Similarly, performing adjustments and transformations on temperature representations of the Earth's surface may pose a context of great scientific significance, but with little connection to students' initial knowledge state.

In light of these observations, our activity designs for the ATDP courses proceeded in roughly two fronts. First, we wanted to provide students with activity types with which they are apparently familiar. As much as possible, we chose to couch scientific image processing activities in terms of design – an approach we (diSessa, 1992) and others have advocated (e.g., Resnick, 1996; Wilensky, 2000). We take this approach as subject to further scrutiny, but we have adopted it as a point of departure.

In the context of image processing, this design orientation was translated into having the object of students' investigations be representations that they construct themselves. For example, rather than giving students "real" scientific data of temperature over a surface, we allowed them to create and edit their own data through the LCK. Likewise, instead of providing canonical representations of terrain, we gave students some props and asked them to construct their own landscapes, which they then photographed and transformed into image data. Finally, as previously described, palette design was a prominent part of several image processing activities, and program design was an extension to proposed activities that was always at students' disposal.

Whenever the "design condition" could not be met – say, because a specific conceptual point might be better highlighted in a different mode – we wanted to pose contexts in which the object of students' actions provided a territory familiar enough for them to perform competently. The Beauty activity, in which one works on his/her own face, provides an example of one such context.

Second, in translating the core practices of image processing work into the classroom context, we privileged students' competence pool, as revealed in formative work, rather than fidelity to scientific practice.[15] For instance, palette making is perhaps a part of the daily practice of scientists who work with image processing-related activities. However, it is not so central as it has been made in our activities.

By the same token, had we translated the tools of science in a strict manner, we would not end up with anything like the PMT. Our implementation of a rich set of palette and color-related functions was a deliberate move to foster students' competent, sustained performance. We think that this approach partly explains why palette making anchored Dean's personal excursions, as well as much of Beth's work on the Cheshire Cat.

6.3. *Time*

By definition, extended classroom engagement is fundamentally dependent upon students being given enough time to pursue assigned and/or self-devised projects. In line with this idea, time has been deemed an important resource by researchers concerned with student engagement (e.g., Engle and Conant, 2002; Blumenfeld et al., 1991).

From the point of view of personal excursions, we can extend arguments about the importance of the time parameter for students' engagement in three important ways. First and foremost, our analysis has revealed that the collection of resources by students is an important part of the process that supports and sustains engagement. Because those resources usually take on relevance to students' self-initiated pursuits in the long run, it is fundamental that students be given enough time for their experimentation, as well as for working on the proposed activities.

In a similar vein, we speculate that time is crucial for students to develop ideas of their own and to try out these ideas in personal excursions. Exceptions to this case obviously exist – e.g., Carl, Cathy, and Beth's experimentation with system graphics capabilities show that sometimes excursions may occur very early in the unit. Overall, however, time should provide opportunities for students' competence and interests to find hooks in framed activities onto which to cling. Indeed, this appears to be the case of Dean's pursuit of zebra-palettes, which was carried out after he had used the PMT several times, and Carl's implementation of his square-stamping procedure during his final project work.

Finally, we believe students are relatively quick to pick up the patterns of classroom norms and expectations, so that weighing their own pursuits in light of larger, classroom-shared goals may not be difficult. In this regard, it is possible that students often embark on personal excursions exactly because they know there will be enough time for them to return to assigned tasks.

6.4. *Environment Nature and Features*

Just as students' competence and interests are major elements that explain how individuals' agency bears on the form and content of their pursuits, the nature and features of the environment (computational, in this case) must explain – without fully determining – what kinds of activities one can possibly pursue, how easily one can express him or herself, what styles of work are possible or better supported, and so forth.

As pointed out in the preceding analysis, the object of students' personal excursions varies widely. Thus, while some students venture into investigations of the effects of different palettes on colored displays (e.g., Dean), others spend time experimenting with the system graphics features (Carl and Cathy).

In a similar vein, styles of work and individuals' preferences are also determinants of personal excursions: Some students are deeply into programming (Beth) whereas others are content to use little or no programming to extend given activities (Carl and Cathy), instead re-purposing tools and other resources to fulfill their personal needs (Dean).

Clearly, the computational medium in which these pursuits are carried out must be flexible and extendible enough to accommodate such a variety of pursuits. Boxer's expressive capabilities have proven key in allowing students to engage in excursions of varying character and complexity.

CONCLUSIONS

In this paper, we have advanced a research program whose goal is to understand the nature of self-directed, self-motivated, relatively long-term student engagement. In pursuing this goal, we began by selecting activity episodes in which students appear to be highly engaged, and then we attended to the fine-grained details of those events.

Our analysis reveals that students engage with framed activities but, in the process of working toward framed goals, students initiate new activities that better match their own personal agendas. Such student-initiated activities – which we have termed personal excursions – may not fully align with the goals of the activity-as-framed, but they often and at best bear some important relationship to those goals. Although personal excursions may take more or less time, the overall trend is for students to resume work on the activity-as-framed, either upon completion of their excursions or for some other reason (say, because the excursion proves untenable).

In considering the excursions of different students, we found a general dynamic pattern of exploration that cuts across individuals. However, we also found that the specifics of individuals' excursions (e.g., what their goals are and when they are initiated or terminated) are widely variable and hard to predict. We interpreted this result as suggesting the myriad ways in which different students relate to ongoing, proposed activities.

In explaining the factors underlying personal excursions, we argued that personal excursions are naturally occurring phenomena when students work on activities that provide them the means to express their competence, when enough time is allowed for extended pursuits, and when material and social infrastructures are flexible enough to accommodate the diversity of interests and goals one is likely to find in a classroom.

Furthermore, we proposed that allowing students to take personal excursions positively affects their involvement with classroom material because: (1) by virtue of their highly relevant personal character, personal excursions function as energy generators in the local and global context of a curriculum; and (2) through personal excursions, students build pragmatic, conceptual, and question-generating resources so that more extended, coherent personal pursuits are possible and more likely to take place.

Of course, much work is still needed and it is easy to imagine at least two major lines of investigation to follow. First, within the context of our own study, it is necessary that we explore the details of personal excursions further. As has become obvious, following our data collection procedures, by necessity our project here has been strongly descriptive. That is, we collected a number of occurrences of students' undisturbed, natural behavior and sorted them out into relevant categories. This strategy has afforded us a characterization of personal excursions and the phenomenology accompanying them. Having developed an understanding of personal excursions, however, we can now resort to additional data collection methods to probe a student's goals and motivations for taking an excursion, the resources acquired during an excursion and how such resources shape ongoing activity, the reasons for abandoning an excursion (in case it gets dropped), and so on. Systematic investigations of this sort might crucially extend our theoretical understanding of personal excursions.

Second, it would be useful to document whether personal excursions occur in different contexts and, if so, to flesh out the particulars of these contexts. For instance, we imagine that alternative classroom activity structures aided by rich, varied forms of media might provide the conditions that free students to pursue their own lines of work, thus somehow supplying the role that Boxer has played in our case. Likewise, group work might provide a context for continued exchange of ideas, thus sustaining one's interest in at least aspects of an excursion. Examining how factors operate to support (or not) personal excursions in different contexts would afford a more precise understanding of the relationships between such factors. In this manner, we could develop increasingly refined design guidelines for classroom environments that foster students' excursions. In order to support a variety of teaching styles, the same process might afford developing pedagogical strategies to manage students' excursions so that collected resources can be made to systematically feed into framed activities or students' future excursions.

NOTES

[1] Inferences regarding ATDP students' overall abilities are based on a comparison across student populations with whom we worked as part of the overarching research project of which The Symbols of Science is a piece. For example, many of the paper-and-pencil activities used in our summer courses were also administered to students in public and private schools, in a number of formats and contexts. Student performance – as measured by the products students generated, as well as their ability to argue with and about such products – was essentially the same across all sites, including ATDP courses. See Sherin (1997, 2000) and Azevedo (1998, 2000) for details.

[2] Field notes were taken by researchers directly on a laptop computer and saved as text files. Field notes are referenced in the text as (Obs_*date*; p. *x*), where *date* has the format *mm/dd/yy*. Video records are cited as (video: *date*), and activity files saved by students as (file: *student-name_activity-name*). All student names are pseudonyms.

[3] A number of practical and technical problems conspired in rendering our lab records relatively poor. Most notably, the use of PZM microphones amplified the usually loud lab environment, making the sound track hard to follow. Furthermore, we opted to aim the camera at the focal group's computer screen. But the camera intermittently lost synch with the monitor image, making it hard to distinguish actions on the screen.

[4] As it happened, Dean and Peter sat next to the focal group. Because both students were reasonably loud, for the most part we can hear more of their utterances than those of any other student, including focal ones.

[5] In presenting Dean and Peter's work, we shift between attributing agency to Dean and to the group. We do so because Dean always took control of the mouse and seemed to dictate the pace of activity work and idea generation. Although Peter was content to go along with Dean's ideas, he often took those ideas as his own goals.

[6] Transcription conventions are as follows: uppercase denotes raised intonation; :: denotes extended vowel sound; ellipsis stand for brief stops in the utterance; analyst's comments appear between (( )); // denotes interrupted or overlapping talk; within a transcribed sequence, successive time stamps signify extended periods of inaudible audio.

[7] See diSessa (2000, pp. 178–180) for considerations of some interesting properties of representational displays rendered with zebra-palettes as compared to more standard contour-based representations.

[8] To expand on this point, one will note that Beth's implementation effectively turns input controls (the MIN–MAX sliders) into output, and output (the rendered image) into an input device. Incidentally, this illustrates an excellent interface design lesson – an example of what Thimbleby (1990) has termed *equal opportunity interface*. Briefly, equal opportunity interfaces provide users a "two-way street" to investigating the effects of their actions. In this manner, Thimbleby argues that equal opportunity interfaces support more

flexible thinking and experimentation (e.g., ''what-if'' queries), and thus have excellent learning properties.

[9] Self-determination seems to appear under many guises. For example, Engle & Conant (2002) use the phrase ''fostering student authority'' in a manner that is very close to the usual meaning of self-determination.

[10] To be sure, Dean had his own way of approaching classroom and lab activities. Early in the course, when working on Boxer tutorials that preceded image processing activities, Dean deviated strongly from proposed tasks (Obs_6/19/97, p. 1). Later, when discussing work on Geezer – an activity that proposes an investigation of the image of an archeological site – Dean admitted having ''cheated,'' deliberately using the data-peeker to solve a task item in which the tool had been explicitly disallowed (video: 7/3/97). By doing so, Dean bypassed the original task goals, but reduced his work load in solving the problem.

[11] As it turns out, in a subsequent whole-class discussion, the teacher used zebra palettes as a tool for thinking about curious effects obtained on images of an ideal pyramid (video: 7/10/97). Zebra palettes – a product of excursions taken by two students – had thus been brought into the public arena and could then be negotiated as part (or not) of the classroom discourse (Gee, 1999, pp. 17–23; Engle and Conant, 2002).

[12] Of course, Dean and Peter may have pursued multiple simultaneous activities, each motivated by one or more goals. Furthermore, one or more of these activities could have been more in line with the activity-as-framed. In any case, the overall dynamics is not altered – that is, Dean and Peter still wandered off in a direction that more fully aligned with their (local or global) interests and goals.

[13] We are inferring ''pride'' from the fact that, of all images Dean created, those rendered with ''special'' palettes were the ones he cared to save to a file (file: Dean_Beauty). Incidentally, as we described in vignette 3, Beth also chose to create a file containing only her cat image and associated palettes (file: Beth_Cat), rather than other images she created during Beauty. We take it that these observations combine to strengthen our hypothesis about the personal significance those activities took for Dean and Beth, respectively.

[14] In fact, if Carl and Beth had similar interests at the beginning of the course, their trajectories indicate they parted ways with the course progression. From our perspective, given the nature of Carl's long-term project, it is easy to see how early graphics-based excursions were relevant to his pursuits, but not necessarily to Beth's. Once again, this illustrates that resources become relevant largely in relation to one's ongoing paths of exploration.

[15] Roschelle (1996) adopted a similar design stance, initially sacrificing epistemic fidelity of representational displays of physical forces for displays that students could more easily understand and, crucially, argue about.

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