Toy Dissection
Formative In-Depth Assessment Report

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This document presents initial findings from a Video Interaction Analysis of Professor Sheri Sheppard's Toy Dissection activity, in the ME99 course at Stanford. The goalsof this document are to: (a) help improve the dissection activity and (b) to contribute to anoverall evaluation of the activity for the Synthesis Coalition. We have prepared a video tape of shortscenes from the class activity, which illustrates our findings.

The Toy Dissection Activity

In this activity, students take apart a wind-up toy, with two main goals: (1) to prepare assembly and disassembly instructions for another student and (2) to describe how the toy works. The toy is a plastic duck, with a pull-out string. When the string is released, the duck flaps its extremities. The students worked in class in pairs or triads over the course of approximately an hour and a half on this exercise. They worked at tables, using a screwdriver, and writing with paper and pencil.

Sources of Data, Issues, and Analysis

We gathered data in three ways. First, we observed the toy dissection class and took field notes. Second, we interviewed Sherri Sheppard and her T.A.s about the class. We were also able to interview most of the students briefly as they worked on the exercise. Third, and most importantly, we videotaped two groups over the course of their classroom activity.

In conjunction with Professor Larry Leifer and Margot Brereton at Stanford, we previously developed a set of four primary issues for analysis:

- Does the activity engage students in learning?
- Does the activity encourage teamwork and communication?
- Does the activity provide opportunities to practice engineering in the ways suggested by Synthesis goals?
- Is the activity likely to retain students in an engineering degree program?

The method we used is Video Interaction Analysis. Briefly, our analysis involves detailed scrutiny of the actual learning events as recorded on video, set in the context of field notes and interviews.

Findings from Direct Observation

Since these observations set the context for the in-depth analysis, we begin with a summary from field notes.

The class consisted of about 20 students, including both males and females, and white and minority students. The class began with a 20 minute presentation by an Asian female student on Velcro. After the presentation, Professor Sheppard told the students to begin the dissection activity. It took about five minutes for them to get situated and start work.
>From that time forward, all students engaged in the activity. They appeared to be working on this task the majority of the time - - very little "goofing off" was apparent. Professor Sheppard and Melissa Regan, her T.A., only interacted with students when they had a procedural problem in completing the task, which did not occur frequently.

Learning

The toy dissection activity appears to generate a very high level of engagement among all students. Students were observed to generate questions frequently and appeared quite confident that they could answer the questions by exploring the device. Thus, a majority of the learning in this activity was generated, initiated, and completed by the students themselves.

We noted that the students do not have any reference materials available and did not interact intellectually with the teacher or teaching assistants during the exercise. We wonder if more interaction could be beneficial. Based on the in-depth video analysis, we look at the extent to which this self-generated learning appears to be successful.

We also noted that the time allotted to the class was too short, and that there was not enough reflection time (students could barely complete the assembly / disassembly task). We suggest that it might be better to choose a non-standard, longer block of time, and / or a less complex toy.

Social

The activity is designed to be performed in teams, and all students worked in groups of 2 or 3. There are many opportunities for learning about teamwork in the task. However, not all groups engaged in teamwork to the same extent. A few groups appeared to communicate quite fully about every aspect of their activity. In other groups, communications were less frequent, with one team member watching as the other teammate quietly worked.

One group reported a "communications breakdown" (in their teamwork). They gave an articulate explanation of how they had been wasting time: Both partners were doing the same drawing. They said it was hard to draw different parts when there was only one device to share. They should have talked about it first. They thought it might have been better to first become familiar with the device, and then decide how to draw it.

We take up the nature of teamwork and communications more fully in the video analysis section, looking at the extent to which teams are collaborating.

Synthesis/Engineering

Upon direct observation, there appeared to be a number of forms of activity that students engaged in. Some students were "twiddlers" - spending the majority of their time with their hands on the device, poking and probing. Other students were "documenters" - spending most their time writing or drawing, and going to the device when they needed information for their document. Of course, some students alternate between these modes. We examine the modes of activity and their interplay in the in-depth video analysis.

In this activity, students were not asked to design an artifact. Nonetheless, we observed several kinds of activity relevant to Synthesis Goals. Students spent time negotiating terminology. They looked upon the instructions and drawings that they were making as designed artifacts that were going to be used by another person. Some groups worked hard on explaining how the device worked; and in all the groups the students worked to relate the parts and structure of the device to its function. We observed most groups generating a causal chain, in which they traced how a sequence of events propagates from one part of the device to the next.

These observations lead to questions about the extent to which Synthesis activity occurred, and the quality of students engineering activity. We take these issues up in the video analysis, where extent and quality can be observed more carefully.

Retention

It is difficult to observe short-term events which clearly portend long-term choices such as whether or not to become an engineer. Nonetheless, it is worth mentioning several observations relevant to the retention. All students, regardless of gender or ethnicity, appeared to be fully engaged in the task. Everyone said they liked the task. Their primary complaint was that they did not have enough time to to work. All students appeared to see themselves as competent to succeed in this task on their own.

Findings from Video Analysis

We performed two kinds of video analysis. First, one research scientist watched the videos from beginning to end, taking notes. Second, a diverse group of assessment experts discussed selected scenes from the beginning, middle, and end of each tape.

Both groups we videotaped exhibited the positive characteristics we observed in the field. The students in both groups worked "on-task" almost all the time. Their learning was self-directed, and they developed knowledge by exploring the toy. Both groups worked as teams, sharing knowledge and negotiating a shared plan of action. Both groups were engaged in Synthesis-type activities. They connected engineering terminology to the device at hand, performed experiments to gain understanding, used elements of a professional practice to structure their work, and considered design implications of their work. Both groups exhibited behaviors that could contribute to a positive attitude towards an engineering career: they described the toy in positive terms (e.g. "cool", "cute"), smoothly made transitions between a commonplace and professional approach to the toy, felt free to express their own thoughts, and acted as if they had sufficient resources to succeed at the task. To summarize, the toy dissection activity is a positive experience for all the students we observed.

Beyond these overall similarities, however, the groups were remarkably different. Field observations suggest that the differences were not unique to these particular sets of students, but rather that these differences appear throughout all the groups. Below we characterize each group and critique their activity relative to Synthesis Coalition goals.

Group G3

This group consisted of three females, two of whom were Asian and one of whom was Black. Observers of the video characterize their work as vibrant and energetic, highly collaborative, as well as carefully monitored and controlled. A chronology of their activity is as follows: From the time of Professor Sheppard's instruction to get started, it took G3 6 minutes to get situated around the table, with the toy, tools, and paper in front of them. In the first five minutes, they negotiated how to proceed on the task ("What should we do first?" "First we'll do a sequence of events").
>From the beginning this group was very active in posing questions about the functioning of the device ("This is a piece of foam core, what's it there for?"), and generating hypotheses about the mechanism that achieved that functionality ("must be some gears inside"). Also from the beginning they actively discussed and negotiated what to do, what to write, and how to understand the device. For example, G3 actively considered who should sit where to best accomplish their respective tasks.

Once they began dissection, the group quickly fell into a stable pattern of activity that included maintaining several lines of inquiry in parallel. As they worked, the students rapidly wove together the activities of:

- experimenting with the behavior of the toy
- taking the toy apart and re-assembling it
- writing instructions
- making drawings
- posing and answering questions about functionality
- negotiating terminology and explanations
- monitoring progress, and the amount of time available

The members of the group took on stable roles. One student spent most of her time drawing, only touching the device when she need to orient it for her sketch. Another student spent most her time taking the device apart and posing questions about functionality. The third student did most of the writing of instructions, but also participated frequently in taking the device apart. Within this division of roles, there was frequent communication and collaboration among team members.

As far as we could tell from the video, G3 progressed smoothly to a complete set of instructions. As they approached the end of the allotted time, G3 began to re-assemble the device. Simultaneously they discussed and developed an explanation of how the device works. This culminated in a written explanation which was read aloud by one group member and agreed to by the others. They smoothly ended their work within the allotted time.

Within this chronology of events, we considered the four issues of learning, teamwork, engineering, and retention.

Learning
G3 was energetically engaged in learning throughout. They posed newquestions nearly every minute. The two most common form of question were "What should we call this?" (learning about terminology), and "How does this work?" (learning about functionality). One notable question was, "Is a cam considered a gear?" This question is relevant both to terminology and functionality, and provided a good opportunity to share knowledge and build understanding of an engineering component.

Simultaneously with posing questions, G3 generated hypotheses ("there must be a third gear that we can't see yet"), and explored the device looking for answers. For example, at one point they pulled and released the string very slowly while carefully observing the behavior of a cam. We noted several references to things they learned in class (e.g. writing a sequence of events) and in previous dissections. We also noted that the students monitored their progress; they noted which questions were satisfactorily answered. When a question was postponed, they came back to it as soon as more information was available. To summarize, G3 were consistently engaged in successful self-directed, exploratory learning with a high degree of self-monitoring and self-confidence.

Social
G3 acted as a team of collaborators. They smoothly negotiated the beginning and end of their activity, as well as a division of roles within the team. Through their team work, the different modes of activity they were engaged in were well synchronized - interruptions were infrequent and conflicts were resolved smoothly. For example, there was an initial disagreement over whether there were 3 or 5 states in the toy's behavior. Each student discussed how they counted the states, and the group arrived at a consensus of 5 states.

G3 maintained a collegial environment which included joking and laughing as well as serious work. When any team member had a question, it was raised and addressed by the group. Frequently these questions were about terminology, and we noted that the team did develop consistent terminology for their hands-on work, their drawing, and their instructions. Questions about functionality were taken as opportunities for all three team members to think together, and the resulting explanations often contained ideas from several participants. At each stage of discovery, the discoverer created opportunities to share their new knowledge with the others.

Synthesis/Engineering
G3 approached the task as engineers. They used professional terminology (e.g. cam, pawl, ratchet, follower, torsion spring, compression spring, catches, engaged, main system, stored energy) and discussed how it applied to the toy. They also used professional techniques, like the sequence of events. We noted several potentially beneficial outcomes: the students appeared to learn about the relations between appearances and mechanisms; they were building a sense for complexity ("These things have so many pieces, its amazing!") and time to complete a task; and they were coping with uncertainty (e.g "we don't know that yet, do we?") and maintaining a controlled strategy for accomplishing a task.

A potential issue is the level to which they use engineering theory in their explanations. A common finding in research which compares experts and novices is that the experts describe things in terms of functional components, whereas novices describe superficial arrangements of parts. G3 tended to talk about things in terms of parts ("gear 3"), where they might have identified functional components ("drive train" or "reduction gears"). One the one hand, they did talk about the spring as "energy storage." On the other hand, their explanations have a quality of "the hip bone is connected to the leg bone, the leg bone is connected to the foot bone" - they trace a very local set of casual propagations rather than identifying high-level functional sub-systems. We are not sure whether this behavior is appropriate for their level of education.

We also note that G3 occasionally attended to their instructions and drawings as a design. In this case, the design was for a dorm-mate. They considered this context, and the appropriateness of their terminology, for example. However, the majority of the time they appeared to treat the instructions as an assignment to be done for the class. We wonder if more attention to the drawings and instructions as a designed artifact could enhance the Synthesis aspects of this task. We also might want to video tape their interaction with dorm-mates in the next iteration of this work.

Retention
G3 is a minority and female group. They seemed to thoroughly enjoy the activity, and were competent and in control at all times. Their team had a mutually supportive flavor, and the class overall lacked the feeling of intense competition that sometimes marks engineering education. We see many reasons why the

members of G3 would want to be engineers based on their activity here, and few frustrations that would lead them away from engineering.

Group BG

This group consisted of one male student (M) and one female student (F). Observers of the video characterize their work as lacking energy, lacking conversational engagement, and primarily focussing on the instruction writing task. A chronology of their activity is as follows: As with the G3, it took BG about 5 minutes to get situated. In the first few minutes, they negotiated the task. M gave low priority to the goal of figuring out how the toy works ("we already know how it works"). F set to work writing instructions, while M gathered a bucket for parts and began disassembly. In contrast to G3, who negotiated the beginning of the task, BG either volunteered or just began their role without comment. BG exhibited a lesser attention to process than G3.

Once they began the dissection, BG also quickly fell into a stable pattern of activity. Unlike G3 they worked on one task for long periods of time. Typically F would quietly write instructions for 2 to 3 minutes while M took apart and played with the device. M monitored the female's progress by glancing at her sheet. In between these long stretches of quiet activity, BG had short conversational exchanges. Many of these were focussed on the mechanics of dissembling the device ("the foot doesn't come off, does it?"). Occasionally they discussed functionality or terminology. There was relatively little explicit monitoring of progress.

Unfortunately, the video tape stopped about 5 minutes before the end of class so we were unable to observe the closing of their activity. As far as we could tell from the video, BG developed a good set of drawings and instructions. However, whereas G3 began to anticipate and move towards closing at least 10 minutes before the end of class, BG made no such moves. In particular, whereas G3 focussed on explanation towards the end of their time, BG worked on instructions throughout.

Within this chronology of events, we considered the four issues of learning, teamwork, engineering, and retention.

Learning

BG worked on the task throughout the allotted time. They focussed primarily on writing instructions (F) and exploring the toy (M). They posed questions. Many of these were about how to disassemble the device, or how to write instructions. Some were about terminology, and some were about functionality. One notable conversation was about whether a spring was wound clockwise or counterclockwise. Another conversation was about the purpose of a particular spring.

BG generated hypotheses (e.g. there must be "two separate winding mechanisms"), and explored and experimented with the device to find answers. In contrast to G3, there was little evidence that BG monitored the solved and unsolved questions, or that they connected new evidence to old questions. Also, in contrast to G3, BG clearly worked on disassembly and instruction-writing most of the time, and spent relatively little time asking and answering questions about functionality. There were no explicit references to previously learned material.

The group of observers who watched the video wondered if BG's almost exclusive focus on instruction-writing was suppressing other useful forms of learning activity. Although BG was self-directed and did generate and answer their own questions, they did not appear to approach the task with as broad an agenda as G3, and did delve into questions with nearly the same intensity. If they were learning much on this task, they were learning things through quiet observation. However, the nature of their discussions and the amount of time absorbed in writing do not suggest they were learning as much as G3.

Social

BG had a stable pattern of roles and responsibilities that allowed smooth progress in disassembling the toy and writing instructions. Whereas G3 read the instructions aloud as they were written, and thus allowed comment and correction, BG worked very quietly. They did engage each other in conversation from time to time, sharing jokes and offhand remarks. Many of the topic-oriented conversations were either one-sided or short. For example, F announced that she didn't see what made the cam stop. After a pause, she answered her own question, and M said, "yeah it works." Similarly, many of M's remarks simply asserted constraints on group activity, e.g. "we should mention that gear in the instructions" or "we can't name the pieces with letters." At one point, there was a conflict over whether F's drawing had the correct direction of rotation of the gear. Rather than smoothly moving to resolution of conflict, the discussion died away and came back several times. Rather than arriving at a shared understanding, M eventually retracted his position ("well I guess you are right"). In general, BG tended to leave conflicts unresolved. In addition, on several occasions M explained a piece of functionality and F exhibited difficulty in understanding. Again, it appeared that these potential learning situations just died away, rather than leading to a shared understanding among both students. In main successful pattern of sharing, F would ask for the name of a part, M would provide it, and F would write it down. In general, while BG did arrive at a productive division of labor, it might not be an effective form of collaborative learning. We have questions about whether they could be more successful at negotiating roles and process, sharing ideas and questions, and working towards joint outcomes, both in their understandings and their work products.

Engineering/Synthesis

BG approached the task as engineers. Like G3, they used professional terminology (e.g., cam, power transfer, stored energy, etc.) and discussed how it applied to the toy. They developed hypotheses, experiments, and explanations that examined how the mechanism achieved the overall functionality of the toy, although as mentioned above, this was not the focus of their efforts. Also BG considered the toy as a designed artifacy and made evaluations ("should be no logical reason for this feature" and "that's a weak design"). In contrast to G3, BG also exhibited more of a sense for functional components in their explanations, for example, describing a "power transfer gear" rather than something like superficial arrangements of parts. Similarly they explain a spring's function as returning a component to a "default" position. However, in contrast to G3, BG did not make any explicit use of a professional approach to the task such as working from a "sequence of events." In general, we were concerned as to whether BG's explanations were as good as they should be, and whether they were spending too much time writing instructions and not enough time trying to understand the design of the toy.

Retention

BG's experience was not as clearly positive as G3's. On one hand, they seemed to enjoy working with the toy and appeared to be confident and competent in their work. On the other hand, BG did not show signs of having major insights or discoveries, and one could interpret their quiet focus on writing instruction and disassembling the toy as oriented to completing a school assignment rather than practicing one's chosen profession. Of course, because they were quiet, we cannot know this conclusively from the video evidence, and so further interviewing with these students would be warranted before reaching a conclusion.

Summary and Recommendations

The toy dissection exercise has many exemplary properties. It uniformly engages all students fully for over an hour and a half. Students exhibit considerable ability to direct their own learning and construct their own knowledge. Moreover, the toy dissection provides an opportunity to practice teamwork and collaboration, and to experience the problems that teams frequently have, such as communication breakdowns. With respect to Engineering / Synthesis, toy dissection strongly exercises students' ability to use engineering terminology in a complex, hands-on setting. Students also use engineering concepts to generate hypotheses, and they conduct experiments with the device to find the answers. They attend to the toy as a designed device, and discover the complexity of real-world systems and the time required for real world assignments. To some extent, they also attend to the instruction-writing task as a design task, with an intended goal for a specific audience. Although retention is extremely hard to predict from short-term probes, we see many positive aspects to this setting. The toy is an object which bridges everyday and engineering contexts nicely. Professor Sheppard has created a very collegial and supportive environment in which students feel free to explore and express themselves. Students find the toy dissection challenging and interesting, and yet are able to succeed at it.. We did not observe significant differences in the activity of different genders or ethnic groups. Professor Sheppard and her T.A.. provide good role models for prospective women engineers.

In the field observations, and particularly in the video-based comparison of G3 and BG, we observed considerable differences in how groups of students seize the opportunities available in the toy dissection activity. Group G3 strived for a broader array of questions, monitored their progress better, shared ideas better, participated more fully in constructing collaborative explanations and documents, and spent more time considering terminology and engineering functionality. Group BG appeared to be better in only one aspect - M's explanations described functional components at a higher level.

Overall, we recommend continuing work on the dissection exercise. We also believe it is ready for immediate dissemination. Toy dissection appears to be a break-the-mold engineering activity with many strong benefits with respect to learning, teamwork, synthesis, and retention.

We also recommend some areas for improvement:

- Experiment with longer time blocks. All the students complained that time was too short. We believe more time for explanation and reflection would be beneficial. One small step to increase the available time would be to make sure that the screws on the toy are not stripped. Both BG and G3 wasted 5 minutes on stripped screws. Another small step would be to speed up the transition into the activity. Students should be able to get started in one minute or two, not five minutes or six. More generally, it would be good to allot a whole afternoon to the activity.

- Consider using a less complex device. The toy is quite complicated to assemble and disassemble in the given time. It is probably too hard a task to write instructions for a device this complicated in two hours, even for an accomplished engineer. Of course, on the other hand, one point of toy dissection is to learn how complex a simple toy can be.

- Experiment with task instructions. We were not convinced that the instruction-writing task promotes a broad range of learning activities. On one hand, it does force terminology questions. On the other hand, it takes a long time and tends to suppress questions about functionality. One possibility here is to ask students to think about how much time they want to devote to each task (i.e. writing instructions and exploring functionality), and how they want to organize and sequence their time. A class discussion could compare the various approaches that students generated and tried. This discussion would create opportunities to discuss the process. Another possibility is to add to a task of "generating three good engineering questions." Margot Brereton has experimented with task, and reports that while it is difficult for students, it does focus their attention on how the hands-on activity relates to engineering practice.

- Explore additional resources. We noted that the students undertake this activity with few information resources. Perhaps the most important resource would be a shared, high quality drawing that all students in a group could use as a point of reference. It is very hard for practicing engineers to make high quality, communicative sketches in real time. It is also hard to communicate about a complex device without a good sketch. We observed students searching for points of common reference that would make communication easier. While sketching is an important part of the task, perhaps it could be restricted to sub-systems within the toy, and students could be provided with an overall diagram. We see this as having two potential benefits. First, it would provide a resource for communication; second, it would provide a reference standard that exemplifies the expected quality of engineering drawings. (Note: we will be exploring this idea further in our analysis of the drill dissection exercise, which utilizes a computer with hypermedia drawings.)

- Explore more teacher involvement. We value the open-ended nature of the toy dissection task. However, we noted that the different groups of students did not perform the task as well as others. We believe that selective probing and monitoring by the teaching staff could dramatically improve the accomplishments of all students. A particularly critical time is the beginning of the task. In the first five minutes, students determine roles and the pattern of activity that they follow for the whole session. In many cases, (both on video and in our field observations), it did not appear that students deliberately planned their work style. The teacher could visit each group and simply ask "How have you decided to proceed?" "What do you plan to do?" "How are you going to work together?" "Have you thought about what you want to learn by doing this?"

We also think that this class could provide a great opportunity for students to experiment with different ways of participating in a team. The teacher could raise team-participation as an explicit topic to reflect upon and discuss. Periodic probes could ask students, "Are you collaborating well?" "What might you do differently as a team?" We believe students find it very hard to ask these questions out loud on their own initiative.

Finally, it appeared that students could use some coaching on how to frame an engineering explanation. Again, the teacher could approach this in an open-ended way by periodically dropping in on groups to ask them for an explanation, and asking questions that lead the students to re-frame their explanation. These periodic check-ins could also remind students to monitor their progress, and re-consider their strategy for completing the assignment.