ENGLISH LANGUAGE ARTS RESEARCH AND TEACHING

Revisiting and Extending Arthur Applebee's Contributions

Edited by Russel K. Durst, George E. Newell, and James D. Marshall

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WRITING THE WORLD TO BUILD THE WORLD, ITERATIVELY

Inscribing Data and Projecting New Materialities in an Engineering Design Project

Charles Bazerman and Brian Self

Arthur Applebee was one of the pioneers in considering the relations of "Writing and Reasoning" (Applebee, 1984) and *How Writing Shapes Thinking* (Langer and Applebee, 1987), as enshrined in the titles of two of his publications that were foundational for research into writing to learn and writing in the disciplines. An important dimension of the reasoning that goes into academic writing concerns the identification, collection, representation, and use of data. The representation of phenomena through data which are transformed into evidence is at the heart of most academic and scientific publications that attempt to represent and reason about the physical, biological, social, and cultural worlds we live in. Since the initial inquiries into disciplinary writing, Writing Studies has made substantial progress in understanding disciplinary genres and how they are located within historically emerged activity systems (see Bazerman et al., 2005 and Bawarshi and Reiff, 2010, for reviews). Writing Studies has also come to understand variation in disciplinary intertextual processes (e.g., Bazerman, 2004) and practices as well as how mathematical, graphic, and other elements become incorporated into academic and scientific writing (e.g., Gross and Harmon, 2014; Kimball, 2013; Hutto, 2008) and how new technologies are influencing the form and processes of disciplinary and professional communication (see Buehl and Gross, 2016). Writing Studies research, however, has learned less about how data are produced and recorded so as to be available for analysis and calculation, the way the data then become evidence deployed in academic writing, and the form the evidence then takes in the written products of different disciplines. Nonetheless, students' enculturation into disciplinary-appropriate practices of evidence use is central to the development of disciplinary competence (Poe, Lerner and Craig, 2010).[1]

Disciplinary practitioners need to learn the proper procedures for gathering data about the world, to form evidence for claims, to inform designs, and to give legitimating accounts of what they have done, so others can understand and evaluate how the data has been produced and analyzed. From the disciplinary point of view, these processes are considered as methods, but they are also writing issues. For example, how do limits of calibration in a measuring instrument then influence how one modalizes or hedges an argument about findings? How much does discussion of possible variables in measuring a phenomenon lead one to go back to try further experiments or collect different kinds of data? Even more fundamentally, how do disciplinary orientation and interests point towards the kinds of data one needs to select, collect, and inscribe, in what manner and with what degrees of precision in order to make particular claims or investigate particular kinds of phenomena? These are deeply rhetorical, strategic choices about representing the material world. These are, in Fleck's (1979) terms, active choices that pursue the passive constraints of natural experience. The researcher cannot determine what numbers will turn up on a recording instrument once the experiment runs; nonetheless, the researcher designs the experiment, chooses the recording device, and subjects the findings to interpretation. Equally, the qualitative researcher cannot control what the ethnographic subjects say, but the researcher selects the questions, choses the recording device, and selects the situations and conditions for observations. Both qualitative and quantitative inquiry must be done in accountable ways, supported by records, in order to provide a legitimating narrative of inquiry. Students must learn the accountable production of data as part of becoming effective writers in their professions and disciplines.

Members of design professions such as engineering, in particular, must first inscribe the material and social conditions that frame the design problem and constrain the characteristics of an adequate solution. Further, design professionals must determine the material characteristics (including costs and availability) of the proposed components. As they then give shape to their design ideas within the iterative processes of planning documents, they model and evaluate the material workability of their plans. Their plans must also include procedures for the material construction of their proposed objects, which guide the construction of a material prototype. They then test the prototype to produce data to be evaluated against initial specifications and to determine whether the materialized design is workable and desirable enough to be reproduced and distributed, usually within a commercial setting, which will have its own material conditions and data gathering and monitoring processes.

Following how students learn to identify and inscribe relevant data to inspire and constrain design reasoning and then collect data on the materialized design can tell us about the interplay between material and ideas within professional writing. This study of a year-long senior team design project completed by engineering students (three in mechanical engineering and one in material engineering) examines four iterative documents produced over the course of the year from the initial concept to the final evaluation report, supplemented by work logs, reflective memos, interviews, and other course documents, as the four-person team develops a low-cost prosthetic foot for a clinic in Honduras. The analysis examines what data students identify as relevant and what they inscribe, based on data gathering procedures and how those procedures and inscribed data change over the year, and then how that information enters into their reasoning at the different stages of the project. Tracing the representation and use of data and evidence over the course of this project can reveal how students are acculturated into practices of understanding, reporting, and reasoning about the social and material worlds relevant to the work of their disciplines. We can see how they build a picture of the social and material realities that direct and constrain their design and then emerge as the substance of their built design.

In the course of this project, we can see the students discovering what it is they need to know to make a successful design, to produce a material prototype, and then to test the success of the materialized design within accepted disciplinary practice. Further, as documents must be produced at various moments in the design process, we see how informational needs, data gathering practices, and evidentiary demands evolve over the course of the project. At every moment we see the world pushing back, resisting, and transforming the representation and arguments that can be supported by data, but only insofar as the students actively consider certain evidence as relevant and gather that data to help them make sense of the situation, needs, and practical solutions. We discover the role of the many different kinds of facts they must attend to, the differing standards and practices that bring those facts into the texts, and the different and specific roles they take in the textual reasoning at various stages of the project.[2] In short, we can see how students, following the evidentiary practices of their field, collect and use data relevant to the moment in the design process to develop a transformative relation with the world—transformative both in their understanding and in the world through the material consequences of their professional work. As we understand these data and evidentiary processes, we can structure activities, instruction, and feedback that will lead student writing into stronger representations and reasoning about the realities relevant to the subject, thereby enabling them to write stronger and more effective arguments advancing and applying the knowledge of their fields.

Method and Subjects

The four-person team in this study consisted of two men and two women in their early twenties who were registered in a required senior capstone project course in the final year of their B.S. degree program in engineering at a public university in California during the academic year 2010–2011, taught by the second author of this chapter. The course *Success Guide* identified responsibilities and procedures for the student project along with requirements for the course, including four mandated reports: a Project Proposal due in October, a Conceptual Design Report due in December, a Final Design Report due in February, and a Final Report due in June. Other requirements included reflections each quarter, logbooks, and several presentations. The *Success Guide* offered extensive recommendations about building team collaboration and management as well as processes for idea development, but did not present much detail on the collection or reporting of data. The *Guide*, however, did include an overview of the design process, directing students' attention to different kinds of data at different moments as part of the ongoing design process.

The team's project to design prosthetics for a rural clinic in Honduras was in the tradition of service learning and supported by an external grant and an internal university travel grant. The work on the project was carried out largely on the campus where the students were enrolled, but there were two site visits to the client's clinic in rural Honduras, in October 2010 and May 2011. During the October 2010 visit, all student members of the team, the course supervisor, and a certified prosthetist/orthotist who served as a consultant to the project spent three days on-site. During the May 2011 visit, the unaccompanied students spent two days on-site. In addition, there were repeated email and videoconference communications between the students and clinic personnel throughout the process.

The primary documents analyzed in this study are the four required reports. The reports were 23, 49, 82, and 109 pages in length including appendices, respectively. We analyzed the four main reports in order to answer the specifications of our fundamental research question: What data do these students consider relevant at each stage of the process? Where did the data come from? How were these data evaluated, used, and analyzed, and for what purposes? To gain further insight into how the data were generated and collected along with other data or data analysis that might have been produced but not reported, we also examined one student's logbook of 148 pages. The logbook was a mandated requirement of the course and was to include notes from meetings with teammates and sponsors, conversations with other relevant people, preliminary sketches and ideas, analyses and calculations, evaluation of data, references, choices and reasoning, along with personal thoughts and reflections. In addition, we had access to student reflections, required at the end of each quarter. The instructor of the course, as coauthor, was able to provide extensive background information, and one student was available to answer specific questions about the project and text production from memory of events four years previously.

The analysis began with entering instances of data (i.e., representation of material situations) into a spreadsheet to develop categories of the kinds of data reported in the four reports, the places they were collected from, the form they were collected in, and the purposes they were used for. Then all instances of the various kinds of data were collected together according to category of data, such as need situation, stakeholders, clinic resources, component characteristics, prototype production, and prototype test results.

The analysis was made simpler by the fact that these four reports were sequential and largely cumulative, with particular kinds of data focused on in each of the reports. Once a kind of data was collected and reported, the text often was carried forth to further documents with few changes. This reuse of previously produced text in further documents (sometimes called boilerplating) is a longstanding practice in engineering, law, and other professions (e.g., Franke, 1989; Kahan and Klausner, 1997). This sequential and cumulative nature of the documents made it easier to identify changes, deletions, or supplementations. It also highlighted the stability of knowledge and reasoning once textually inscribed.

We then constructed a narrative of emerging textual symbolic objects, tracing them back to see how the relevant data for each were gathered, under what circumstances, and why, as far as our records and interviews allowed. We also traced them forward as their textual representation changed based on further information gained in the design process, data gathering, and changes of relevance as the design coalesced and led to the production of a prototype, which itself became an object for data representation and reasoning. This is the narrative we present here.

Project Initiation

Engineering design work often begins at the meeting of the engineer or engineering team and a client who needs something built. The original contact occurred when one of the students visited the clinic in the summer of 2010 as part of an educational trip sponsored by a nongovernmental organization interested in engineering interventions for public health. Based on initial observations and discussions, the student proposed designing prostheses for the clinic as a possible team project for the senior capstone project. With the instructor's approval, the student gathered a team of her classmates to work on it. The project was formally initiated within the course structure by a letter to the director of the clinic on September 28. Although the team initially investigated knee replacements and ankle adapters that connect the foot to the leg as well as foot prostheses, they decided after evaluation to use existing solutions for the knee replacements and ankle adapters. They then focused their attention on the foot, which is the subject of our analysis.

Identifying the Need and Client/Clinic Situation/Capabilities

The initial proposal submitted in October shortly before the students left on a fact-finding trip presented no local details of the need, relying on global WHO statistics. The team was aware the clinic's clients were poor Honduran amputees, but had no particular knowledge of the people and organizations or even the size of the Honduran problem. The following is a typical example of the use of global statistics from the October need statement, indicating lack of local knowledge:

> There are 300,000–400,000 known landmine-related amputees, of whom 20% are children. In all, it is estimated that there are up to 500,000 total amputees worldwide, and that 5,000–10,000 are added to this number each year. The ability to receive prostheses can affect the livelihood of an entire family. For instance, working men are often injured on the job due to mine explosions or in accidents involving trains.
>
> (October, 1.2., p.3)

After the visit in late October however, in the December Conceptual Design Report, the need statement became much more detailed and included local facts gained from interviews, as documented in the logbook. For example,

> Many of the patients at [the clinic] had one or more limbs amputated due to injuries sustained while stowing away on trains bound for the United States.
>
> The patients we interviewed described how they "had the American dream" and sought the opportunities available in America. This illustrates the condition that many Hondurans live in and why it is so important for them to be able to work.
>
> (December, 1.2, p. 6)

Also first reported in December were the patients' particular problems with previous prosthetics in terms of rapid loss of alignment and quick deterioration.

> Components that maintain alignment for at least six months will cut down the number of trips they have to take to the clinic each year. Furthermore, prostheses with longer life and lower initial cost would cut down the overall costs for each patient.
>
> (December, 1.3, pp. 6–7)

These issues of alignment, deterioration, and cost were to become defining evaluative parameters for the remainder of the project. Along with other needs expressed by the stakeholders, these issues were included in the main categories in the House of Quality Matrix (a graphic technique for guiding product development; Hauser and Clausing, 1988) introduced in the December report: natural gait, weight, adjustability, durability, producible in-house, aesthetic, easy to manufacture, cost, safety. This matrix was then to remain as a set of goals and criteria for evaluating the emergent design and product and, therefore, entered into the testing procedures discussed below. Here, we see concretely how evidence of one kind (the reality of patient and stakeholder needs) enters operationally into the ideation and design process and leads to data gathering that can be used as evidence for evaluation of the prototype.

Attention to specific conditions also influenced the team's dispositions and emotions concerning the value of and motivation for their work. One team member reflected, "Prior to this trip our team was feeling frustrated and uncertain of the direction of our project, but through this incredible contact with our client and sponsor, we were able to get a much better feeling for our project and how we could be most useful." Another reflected "After meeting with clinic staff and patients and realizing how wonderful they are, I felt that we have a responsibility to provide them with the best possible prosthetic limb."

Despite the importance for the project, this information gained from observation and interview—guided by a few pages in the course *Success Guide* and the supervising instructor—was collected under different standards than would be the case in some social sciences, such as in anthropology or sociology. In these disciplines, students would have taken multiple courses in ethnography and would have been trained in methods of interviewing, observation, and the keeping of field notes to get at, for example, the situational details or phenomenological perspective of the subjects. Further, they may have been expected to spend periods of months or years among their subjects. Here, the concern was only to record in the logbooks a few focused answers to informational questions gathered in a short visit. After this field trip, knowledge of patient conditions and needs seem to be adequate for the rest of the project, with the language describing the patients remaining constant through the final draft.

While the patients would be the ultimate beneficiary of the design, as in most engineering projects, the intermediary client is the deliverer of services, which has its own set of capabilities and interests which need to be served. From the beginning of this project, the main point of contact and partner in the enterprise was the clinic in rural Honduras. In the initial October proposal, a few facts about the history, accomplishments, and funding of the clinic were reported, based on public documents.

> Since its opening in 2003, the clinic has provided 369 new prostheses, 1,278 orthoses, and performed 521 repairs on prosthetic and orthotic devices. The clinic treats approximately 70 patients per year, including both children and adults.
>
> (October, 1.3, p. 3)

Before the visit, equipment and capabilities were known only generally.

> The clinic currently has all the equipment it needs to fit prostheses and may have enough to manufacture components as well. This includes basic tools (files, drills, saws, etc.), a drill press, a lathe, an alignment rig, an oven, and a vacuum pump.
>
> (October, 1.3, p. 4)

Notice the hypothetical "may" in the first sentence, which needed to be confirmed on the site visit through observations and discussions with the technicians and other operational personnel. The confirmed capabilities became embedded in the assumed tools and procedures for manufacture specified in the February report; for example,

> The cuts needed in order to manufacture this concept are all at right angles or could be made using a grinder, and the entire design could be fabricated with tools no more complicated than a band saw and drill press.
>
> (February, 3.1.2, p. 18)

In June, these capabilities were embedded in the report on the prototype manufacturing process, as discussed below.

Another partner identified in the October report is the Rotary Club in La Paz, Honduras, which had been supplying prostheses for 15 years. Other stakeholders operationally significant for the product became more evident on the trip and were added in the December report, including the technicians, a U.S. prosthetist who accompanied the team on the site visit, and a patient who hoped to start a prosthetic business. The survey of stakeholders in the December report becomes stabilized in a chart of stakeholders in appendices in the February and June reports.

Developing Design Specifications

In the October proposal, no specific design is proposed, but existing knee, foot, and adaptive interface designs taken from journals and textbooks were reviewed and citations given. These were also compared as to their benefits and difficulties, with some of the reasoning for comparisons taken from the literature and others having to do with appropriateness for the clinic setting and clients as set out in the stakeholder client section. Further, design goals were formulated as engineering specifications, given in tabular form in Appendix B of the report. This table was repeated as an appendix in December. This specifications table was then brought forward to the main text in the Febrúary and June reports, following the instructor's suggestion, thereby becoming an essential part of the design narrative defining the material constraints the design must meet. Table 6.1 presents the foot component of the specifications.

Most of the specifications table remained constant across all four reports, but there were a few substantial changes to the foot requirements. Starting in December, "Dorsiflexion, plantar flexion, inversion, and eversion" was renamed "Tibial Advancement and Arrangement." Also four categories of specifications were added in December and stayed throughout: Shape and Sizing (fit shoe or external soling); Proof Load Bearing; Ultimate Strength; and Fatigue Strength. All of these are

TABLE 6.1 Engineering specifications for ankle-foot system

Spec #	*Parameter description*	*Requirement or target*	*Tolerance*	*Risk*	*Compliance*
1	Heel strike force	2.5 N/kg body weight	Min	H	A,T
2	Ankle-angle response	Actual response	±50%	M	A,T,I
3	Manufacturing	Mill	Max	L	T,I
4	Deterioration	<5% in 3 years on highly distressed roads	Min	H	A,T,I
5	Dorsiflexion, plantar flexion, inversion, and eversion	Normal	Min	H	A,T,S,I
6	Cost	<$30	Max	L	A,S
7	Weight	0.23–0.8 kg	Min	M	A,T,I

Source: October, App. B, p. 18

specified according to ISO standards. Since the team discussed the ISO standards in October, these were already implicit, but as the team continued work on the project, they found they needed to be more specific about the requirements. One category was added for pylon—"Interfacing: with all pylon adapters"—which again appears to be making explicit an implicit requirement.

Stability of Problem, Resources, and Alternatives

In the December conceptual design, after the site visit, the existing foot design section remained the same with no new facts or reasoning. Thus the specifications and relevant design models seem to stabilize early on, with the site visit focusing attention on a few models and issues and the specifications remaining mostly constant with some added explicitness. These stable elements in essence have become facts about the situation, need, and design targets that guide work from this point forward, ultimately guiding the production of a new material object.

The major change after the site visit was a focus on materials. A casual observation reported in the logbook that empty soda bottles lined the streets led to the idea that the Polyethylene Terephthalate (PET) bottles might be the source of plastic for the fabrication material. Since there was a materials engineering student on the team, this possibility seemed worth investigating. In the December report, a review of fabrication material appeared under the ideation section, including one figure comparing polypropylene (PP), PET, and Delrin with respect to tensile strength and Young's Modulus and another comparing density and price of the same three plastics. The data presented were from a standard textbook and thus common knowledge in the engineering world. This information was then moved to the design review section of the February and June reports with only some wording changes.

Conceptualization and Ideation

The initial Proposal Report established the need and gave the specifications and a comparison to existing devices—effectively defining the design space. The team then began product ideation and brainstormed as many possible solutions to the problem as they could. This involved breaking the overall project into subsystems, including the knee, foot, pylon, connector, and ankle.

For the February report, a Pugh Matrix was constructed for each subsystem—an example of this matrix, for the foot, is shown in Table 6.2. The Pugh Matrix is a structured decision tool that helps engineers rate different concepts according to principal design criteria (Cervone, 2009). The criteria are shown in the first column, and the current product that best meets the criteria is provided in the second column. Each of the initial five design ideas are then rated (better = +, same = S, worse = −) and a total score is provided.

To aid in eliminating alternatives, the students also performed mechanical analysis of the rim foot and the layer foot (their top two choices). This analysis required using computerized analysis tools to calculate mechanical stresses and flexibility of the

TABLE 6.2 Pugh Matrix

	Concept	*Rim foot*	*Layer foot*	*Block with cushion*	*Molded plastic foot*	*Simplified C-foot*
Criteria	Comparison	1	2	3	4	5
Manuf. in-house	Shape and roll	+	S	+	–	–
Effective gait repro.	Niagara	–	S	–	–	+
Low cost	IRC SACH	+	+	+	–	–
Min. deterioration	Niagara	–	S	–	S	S
Long life	Jaipur	–	+	–	–	S
		−1	+2	−1	−4	−1

alternative designs and matching them against the published characteristics of the materials. Further, the analysis helped determine appropriate thicknesses and shapes for the layers of the foot. After the initial analysis reported in December and expanded in February, these analyses were reported without change as an appendix in June.

Product Realization Process

As the design became stabilized in the February report, the next step was to produce working prototypes in various thicknesses to be tested. The process needed to respect the manufacturing constraints of the clinic's capability and resources, determined earlier. Accordingly, the two-page, seven-paragraph narrative of product realization turned the goals of manufacturability into procedures and turned the names of tools (drill, saw) into verbs (drill, cut) and names of resulting actions (cut); for example,

> We experimented with different techniques for cutting out the layers of Delrin. Initially, we used a table saw, which produced straight cuts, but [the clinic] does not have a table saw. We then tried using a handsaw, which worked, but took an additional hour and a lot of additional effort. This is a viable technique but it is very time consuming and would limit the number of layers a technician is able to cut out in one session. Finally, we tried cutting out the sheets with a jigsaw. While extra care was required to ensure accurate cuts, cutting out the layers did not take more time than the table saw. In addition, jigsaws are fairly low cost and would be a worthwhile investment.
>
> (June, 5, p. 33)

Notice how not only the available tools and the potential cost of any additional tools, but also the time and effort for different techniques were taken into account.

Each aspect of the manufacture presented problems in accuracy, ease, cost, and available tools. The narrative ultimately defined a usable process for manufacturing and presented clear instructions for replication of the team's construction techniques. Nonetheless, the team also identified additional planning steps needed for regular manufacture, such as developing procedures to maximize material use through more efficient cutting and turning procedures into a step-by-step manual. The procedure that was planned within the design was iteratively made workable and improved in practice to then create instructions for future replication.

Testing

After the design was finalized in the February report, the students developed their test plan. From the beginning, the team was aware that the produced design would have to be tested to meet ISO (International Organization for Standards) standards for prostheses. In the October proposal, an introductory paragraph acknowledged the existence of the ISO standards and the necessity of meeting them, with two further paragraphs describing the specific tests required and typical testing devices. A final paragraph described the specific environmental conditions that the materials must meet and the relevant standards for the ASTM (American Society for Testing Standards). The relevant organizational documents were cited along with an article describing a device to be used. These last three paragraphs were reproduced verbatim in the December Concept Report. However this documentary information on testing was not repeated in the February design review, at which time the actual testing was about to be implemented. Rather, the ISO standards served as implied background to one subsection (5.2.2) devoted to ISO testing within the component testing section.

Materials Testing

Before examining the component testing, however, a look at the materials testing, also reported in February, which resulted in not using PET in the final design will reveal how data collection and evaluation guides decisions. Deciding what to include in a design and framing a warrantable argument for that design are important skills in academic and particularly engineering writing. Negative decisions are perhaps even more revealing than positive decisions because they put in relief the procedures and criteria used to judge data as unsatisfactory and mark the consequences for paths not taken.

While it was well known that PET could be recycled to ASTM standards with elaborate and expensive machinery, the issue here was to recycle PET to these standards within the limited resources of the clinic. Accordingly, the first attempt to recycle PET assumed that any working furnace with a functioning temperature control device would do and that manipulation of the device required no special monitoring or reporting of technique and procedures.

> The first test was of simply melting cut-up recycled soda bottles in a furnace at 75°C (this is the glass temperature of PET, or the point at which secondary bonds between polymer chains begin to break, creating a more ductile, pliable plastic). We then raised the temperature to 175°C and held it there until the total furnace time was 50 minutes.
>
> (February, 5.1, p. 35)

However, when this simple procedure failed to produce a consistent material, the team became more detailed in further tests in reporting apparatus and procedures as they tried to identify and resolve the processing difficulties. By the third test, the team monitored and reported the process with greater precision, attending to new elements now considered relevant.

> Our mold … had the outer dimensions of 9 × 9 × 0.8 inches and inner dimensions 6.2 × 6.2 × 0.6 inches (Figure 5.2). The mold was filled to the top with virgin PET pellets (i.e. newly made, not recycled) and then placed in the compression molder at 425 degrees Fahrenheit under 4,500 lbs. After three minutes the pressure was raised to 7,500 lbs. for another three minutes. We removed the mold from the machine but when we checked the material it was clear that it had not yet melted. We returned the mold to the machine and raised the temperature to 520 degrees Celsius and held it there for ten minutes under 4,500 lbs. We quenched the mold in cool water so we could open it and remove the melted plastic.
>
> (February, 5.1.2, p. 36)

The result was again unsatisfactory according to criteria of consistency of melting and in terms of the resultant material. Nonetheless, the more precise instrument and careful recording of calibration allowed fourth and fifth comparative trials, which also failed to produce adequately consistent material.

In the final June report, the Materials Test section repeats the February report almost verbatim, though with the deletion of final sentences about future plans. In their place, newly implemented procedures are described in even greater precision and detail, including the composition of the mold and the type of pressure gauge on each of the test runs. Procedures and parameters are then reported in a table for each of the new and previous runs. Despite the attempt to calibrate procedures, the material still failed to reach the desired consistency. Photographs of three samples graphically illustrated the failure to meet the goals for materials processing. The persistent attempts to track down the causes of failure to meet testing standards and to pursue more precise production that might meet standards reveal the power of criteria to drive work and determine decisions. Ultimately, the inability to meet the standards despite a series of iteratively more careful attempts determined that recycling could not be included as part of a viable design.

The failure to recycle adequately and the consequent decision to use a purchasable product (Delrin) made the ASTM standards and testing less relevant.

Consequently the account of the ASTM testing procedures vanish and the ASTM standards appear only in appendices to the February and June reports describing Delrin, whose compliance has already been standardized, tested, and certified by the manufacturer:

> Primary Specification (Resin) (Typical) ASTM-D-4181 POM110B34330
> [...] Shapes Specification (Typical): ASTM-D-6100 S-POM0111
>
> (February, App. D, p. 64)

Component Testing

The success in creating a workable prototype of the prosthetic foot meant that the ISO standards remained relevant throughout the testing process. Although different ISO standards were discussed, due to time and resource limitations only the static testing was ever performed. The February report provided plans for two tests and description of typical devices used for these tests: a structural test explicitly required by ISO standards (presented in sections 5.2.1 and 5.2.2) and a roll-over shape test (not explicitly required by the ISO but commonly used to assure patient comfort and evaluate gait). In February, the test for static ultimate strength required by ISO was described in general terms. In the June final report when the actual testing and results were presented, however, the ISO static strength test specifications were given more precisely because they now provided the relevant target to be met.

> ISO testing procedures as described in ISO standard 22675. These standards specified load control testing at a rate of about 175 N/s up to 4,454 N on the forefoot and 4396 N on the heel. We designed test fixtures to hold the foot at the prescribed angles. The test specified a 15 degree heel loading angle, 20 degree toe loading angle, and 7 degree toe-out angle, as pictured in Figure 6.1.
>
> (June, 6.1, p. 35)

The schematic diagram repeated from the February report is, in June, followed by a narration of instruments and procedures, including all the difficulties encountered in adapting available test devices to simulate the standard devices. Difficulties included the foot slipping off the test device and positioning the foot to allow proper load distribution. Corrective procedures were described and reported as implemented. The details of the difficulties, problem-solving, and practical remedies served as arguments for the integrity of the data concerning strength, flexibility, and elasticity. The final setup would not, however, allow testing of the effect of repeated use, nor could it simulate typical gait. Thus, while these tests were promising, they did not establish the design as fully certifiable for production.

Rollover testing could be accomplished by a standard testing device, whose functioning could be simulated by modifying devices available to the students in their laboratory, as they described in the February report. Due to time and resource constraints, however, as described in the June report, the team followed the alternative of patient testing. In both cases, the prototype was used by people who already had used other prostheses, so they could compare the comfort and effectiveness of the new design. In the United States, the tests of two clients included videotaping of motion, measurement of weight force distribution, and patient subjective reports. The video data was displayed in a figure indicating the heel strike force from the kinetic testing, but there was no discussion. Subjective evaluation from the test subjects was used to rate ankle-angle response as well as flexibility (technically dorsiflexion, plantar flexion, inversion, and eversion).

At the Honduran clinic, the team visually observed six clients using different versions of the prototype matched to client weight and size and listened to their subjective reports about comfort and gait. The prototypes were further modified with locally purchased Vulcrepe material to adjust for height. There were other trim modifications and adjustments to fit individuals.

Overall Project Evaluation

Manufacturability had already been tested through the making of the prototype as reported in the narrative. Costs were calculated again from the actual materials used for the prototype, and these were specified in a table (June, 4.2, pp. 27–28). The biggest challenge to manufacturability and cost-lowering would be the use of recycled PET, but this was eliminated because of the difficulties encountered in the tests. Effective gait reproduction was evaluated by the client testing. Durability consisting of minimal deterioration and long replacement interval was not tested, however, and this would be needed before regular production.

Conclusion

Creation of engineering designs must be situated within a complex multidimensional world and must serve users within it; further, as the design emerges and is produced, its workability and value must be projected and then demonstrated. Data is gathered and recorded according to disciplinary standards, and data from other sources also must be brought to bear on the planning and reasoning. The relevance of data to be collected (or carried forward from prior documents) at each stage depends on disciplinary expectations, standards, and procedures; the temporal unfolding of the project and work; and the particularities of the emergent project. At every stage, data-rich documents must inform, guide, accompany, warrant, and ultimately certify all these stages of work to qualify the new product design and to gain material commitment for its reproduction. The data and reasoning are built across the sequence of documents, each attending to and fixing knowledge necessary to continue on. Data at each stage becomes stabilized as knowledge in textual representations that are carried forward in later reports. In October, the entire project is hypothetical with actual knowledge of the situation and possibilities quite sketchy. By December, knowledge of needs, stakeholders, clinic capabilities and constraints, and already available solutions are stabilized. By February, the design and materials are fixed; and by June, the prototype and its manufacture have become material facts.

The success of creating a new object (the work of engineering) depends on understanding the socioeconomic needs of clients, the conditions of use, and the capabilities of production. Then a design idea must be found which meets those constraints along with the constraints of the material or processes to be worked with. The design must be producible, successfully produced, and tested to perform successfully in the world—and ultimately to be economically and socially viable to be produced and used. If the product were to go to manufacture, additional regimes of data relevant to finances, manufacture, marketing, safety, law, regulation, and other issues would be needed and would be presented in various kinds of reports. Thus the writing and writing choices are deeply implicated with the materialities of the world, which are represented in the text, reasoned about, and then planned and calculated to direct the making of a new object, then to be tested for its effectiveness and robustness and assessed for its organizational value. The writing is about the world that might benefit from the design and the changed world the design brings into being. Accordingly, the reasoning expressed in writing and evoked in the process of writing is intertwined with the experience of the material and social world students are learning about, as enacted through disciplinary procedures that students are learning as part of their projects. Through writing grounded in data, students are developing a relation with the material and social realities around them. This is one more extension of Applebee's early insights into the reasoning we teach when we teach writing.

Notes

1 The production of data and its use as evidence in academic argument are also crucial areas for research in science studies, bearing on basic epistemological issues that became the flashpoint of the science wars of past decades (for example, Knorr-Cetina, 1981; Latour and Woolgar, 1979; and Gilbert and Mulkay, 1984, on one side and Sokal and Bricmont, 1998 and Gross and Levitt, 1994, on the other). The cultural relativist position has continued to be explored through studies on visual representation of data (for example, Coopman, Vertesi, Lynch, and Woolgar, 2014; Hentschel, 2014). But the inscription of data and their evidentiary uses can most usefully be seen not as epistemological debating points, but as sites for empirical investigation of inscription practices within the material practices of disciplines and disciplinary education, as in this study.

2 The well-known relevance theory of Sperber and Wilson (1995) focuses on the generalized cognitive processing of communicative situations, but does not provide specification of how relevance varies from situation to situation. The current study provides some insight into how relevance is discipline and project specific and even how relevance changes over time as situations evolve.

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