# Rapid Scout: Bridging the Gulf Between Physical and Virtual Environments

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## ABSTRACT
We explored how to bridge the gulf between physical and virtual environments for the sport of whitewater paddling. Field observations, critical incident analysis, exploratory prototyping, and field and lab evaluations were used to make discoveries. Lessons learned in this ethnographic process led to the design of a guiding, communication, and navigation aid for kayakers and canoeists. In designing "Rapid Scout", we gained insights on making virtual representations context-sensitive, coupling multiple perspectives, dealing with uncertainty, and extending human views. Ways to facilitate collaboration through shared graphic frames of reference were also explored.

### Keywords
Visualization, representation aiding, groupware, decision support, portable computing, and ethnography.

## BACKGROUND
Our senses are exposed to an ocean of information in the physical world. Computers allow us to add to what is naturally available. Yet a gulf often exists between the physical world and the virtual worlds we create on computers. Not only do we have trouble finding relevant information, but we often find that virtual representations are disconnected from the "real world" entities to which they refer. For instance, virtual representations may fail to highlight changes, or their level of abstraction may be irrelevant to user tasks. Given problems like these, better mappings between the virtual and physical are needed. †

Bridging the gulf between the physical and the virtual requires discoveries on several fronts. More knowledge is needed about coordinating multiple virtual perspectives with existing physical views. Issues also arise in putting data into context, choosing frames of reference, and indicating limits [1]. Moreover, means to enhance cooperation between people must be explored because virtual artifacts are inevitably used in group settings.

### The Natural Lab of Whitewater Paddling
We chose the whitewater domain to serve as our natural laboratory, because it contains challenges and constraints relevant to coupling virtual and physical worlds (Figure 1). Critical characteristics inherent in other complex domains include a dynamic noisy environment, high stakes, uncertainty, multiple players, as well as varying tempos and demands [2]. Due to the extreme nature of this risky environment, these characteristics take on forms that create significant challenges and opportunities.

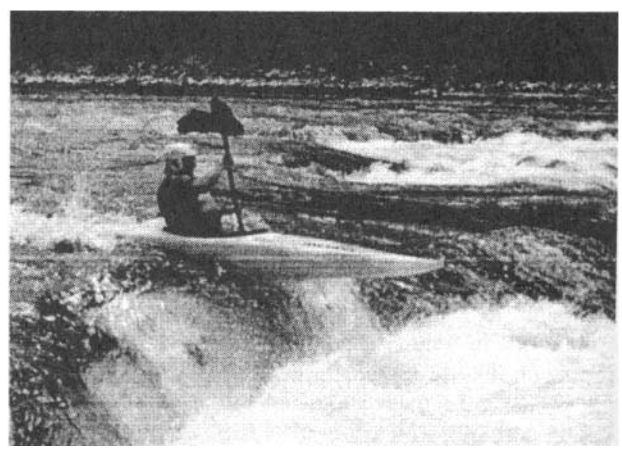

**Figure 1.** The domain of whitewater paddling. Kayaker paddling over a ledge on the New River in West Virginia.

In particular, the complexity of the hydrotopography of rapids offers fertile ground for representation aiding. The dynamic flow, river bed shape, and obstacles combine to challenge a paddler's judgment and maneuvering ability (see rapid in Figure 2). It takes years to learn how to observe, abstract, and judge what the subtle signs mean at different water levels (i.e., the process of "reading water"). Paddlers rely heavily on scouting and communicating with others to

† Apple Computer, Inc. organizes an annual design project to provide students with user-interface design experience. In 1995, the theme was integrating physical and virtual worlds.

manage risk. Novices and experts alike actively seek and share information.

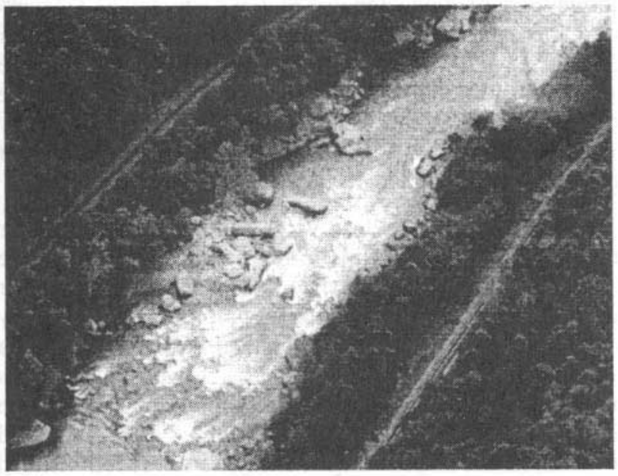

**Figure 2.** Aerial photo showing rapid hydrotopography.

What are the challenges that make bridging the gulf between the virtual and the physical in this domain difficult? Of most importance, representations must complement what paddlers see in the physical world. How did we achieve this? We explored means to extend views by showing what is hidden, obscure, or impossible to scout. We learned how to teach paddlers to read water by highlighting the relationships which matter to them. We discovered new techniques for showing contrasts and abstractions. And, we explored new ways to enhance collaborative activity. The lessons learned from tackling challenges like these can be generalized to other domains in which close virtual and physical coupling is important.

**Overview of the Design Process**

Our design process can best be characterized by an analogy to the domain we studied. Designing Rapid Scout was comparable to running a river with many hazards, channels, tributaries, pushy currents, and possible routes. We faced diverse obstacles that formed a constraint space in which we had to maneuver. In the beginning of the ten-week project, we selected a user group which we felt could benefit by a closer coupling of physical and virtual environments. We then immersed ourselves in field investigations, where we discovered that our initial model of activity in whitewater paddling was incorrect and that there were significant opportunities for providing guidance through an on-the-river device. Once the general Rapid Scout concept was selected, we produced and evaluated in parallel exploratory prototypes for the representation, communication, and hardware elements in order to discover further requirements.

A map of our design process is represented in Figure 3. There are three main sections in our design process: (1) our initial model of the domain, (2) field investigations to revise our model, and (3) continuous exploratory prototyping and evaluation. The map summarizes our methods, findings, challenges, and their implications for the design of Rapid Scout.

## The Rapid Scout Design Process

### Starting with a folk model of the domain

We had doubts that an on-the-river aid would be successful due to several assumptions which we overturned

- Thrill seekers intent on pushing their limits would avoid decision aids
- Naturalists would resist computerized devices
- Paddlers depend on their own skills and judgment
- On-the-river aid would distract the paddler

### Studying cognition in the wild

We developed a model of domain demands, artifact functions, and user requirements through ethnographic investigations.

| Methods | Field study findings | Design implications |
|---|---|---|
| • Domain artifact examination | • Noisy, complex waterscape | • Highlight important relationships |
| • Field observation | • Water level greatly changes difficulty | • Tailor representations to flow context |
| • Incident interviews | • Even experts are information hungry | • Highlight change and events |
| • Newsgroup probes and surveys | • Available physical views are limited | • Extend user perspectives with virtual views and abstractions |
| • Knowledge elicitation | • Information is frequently incorrect, missing, or stale | • Allow users to annotate, update, and share information |
| • Task analysis | • Class rating system is insufficient | • Provide basis of class ratings for rapids |
| • Sport participation | • Communication breakdowns due to ambiguity and under-specification | • Provide shared frame of reference |
| | • Safety and temporal constraints on use | • Don't interfere with swims or wet exits |

### Developing the Rapid Scout concept

During design, we used exploratory prototypes and several evaluations to discover new requirements while refining the product concept.

| Methods | Design challenges | Evaluation findings |
|---|---|---|
| • Interviews | • Selecting and coordinating views | • Tailoring representations to current flow reduced confusion |
| • Scenario-driven development | • Showing relationships and limits | • Representations captured essential relationships |
| • Cognitive walkthroughs | • Layering advice and its information basis | • Targeted and open communication means are warranted |
| • Flip book evaluation on the river | • Coordinating frames of reference | • Texture maps should better denote flow aspects |
| • Usability testing in the lab | • Filtering out noise | • Transitions between views should be streamlined |
| • Observation of similar domains | • Extending views to show what is hidden | • Five new hardware constraints discovered |
| • Physical mock-ups | • Creating micro/macro representations | |
| | • Supporting route planning / decisions | |
| | • Portable computing in a "rough" world | |

**Figure 3.** Overview of design process.

## STARTING WITH A NAIVE FOLK MODEL

All designers begin with an implicit or explicit model of cognitive activity in a domain. Generally, this model should be viewed as tentative and should be tested by ethnographic investigations. We discovered through field observation that our initial model of whitewater paddling was incorrect. First, we considered paddlers to be either in a thrill-seeking or a back-to-nature camp. We were concerned that individuals intent on pushing their limits would not want any decision aids. Likewise, we were concerned that the back-to-nature contingent would be resistant to computer technology on the river. We also believed that the sport was not team-oriented in that paddlers depended on their individual skills and judgment. Lastly, we were concerned that the paddlers would be preoccupied with the activity of paddling. The tempo would be too high to permit any motor, perceptual, or cognitive interaction with a computer aid.

Through field research, we found that these assumptions were simply not true. Paddlers tended to be cautious decision makers, information hungry, and very reliant on others. Their desire for more accurate information due to risks already led them share information using technology (e.g., the World Wide Web). We also discovered that significant opportunities for interaction with a device do arise. A paddler's hands, eyes, and mind are free at many times (e.g., on flat water sections between rapids, scouting on shore, and resting in the eddies/pools within the rapids). The distribution of these locations still place severe constraints on when a paddler can use a portable computer, but designing around these constraints offers new insights on how to simplify interaction in virtual worlds.

## STUDYING COGNITION IN THE WILD

### Comparing Artifacts and Analyzing Tasks

We began our exploration by comparing existing domain artifacts to see how they functioned as cognitive tools and supported collaboration. We looked at formal media such as guidebooks and instructional videos as well as the user-created forums on the World Wide Web. The lively web exchange of advice and stories stressed that paddlers actively seek information. Advice tailored to different river levels and complaints about guidebook inaccuracy stood out. This finding pointed to the need for context-sensitivity.

While examining these artifacts, we also developed a model of the tasks involved. At the highest-level, running a river can be broken into five stages: putting in, paddling flat water sections, scouting rapids, running rapids, and taking out. The detailed cognitive models of these stages prepared us for observing and asking questions.

### Field Observation and Corpus Building

Our strategy was to ensure usefulness by grounding ourselves in the domain and by not committing to one design direction too early. Paddlers were observed during three field trips to the New River Gorge in West Virginia. We rafted the river to gain first-hand knowledge of its features so that we could ask relevant questions. We also watched guides teaching others about the river. Over 30 interviews were conducted in which we adopted an incident-based approach to elicit what paddlers know best (i.e., their experiences with close calls and accidents). Using the critical decision method, we asked paddlers to tell an entire story and then we followed up with questions to clarify critical decision-making points [3]. This corpus of incidents was used to identify ways to aid paddlers.

In the interviews, paddlers were encouraged to draw or annotate diagrams of rapids to help recall and explain the situations. In the example shown in Figure 4, the kayaker did not make a turn in time and was temporarily pinned by an undercut rock. He had not realized how much harder a previous day's route would be at a lower level. This pointed to the need for route recommendations that are tailored to different water levels. His story also indicated the need to show boat angle and size on recommended routes as well the relation of the route to flow strength and direction. In general, incidents like this one emphasized the need to put data into context and highlight relationships.

To further build our corpus of critical incidents, we found the Internet to be a fruitful source. In the paddlers' newsgroup, we monitored postings and sent out probe messages to see what information people share. A critical incident survey was also posted. Many stories of mishaps were described in the posts. Advice on running specific rapids abounded. We also came across postings warning others about new hazards which unpredictably arise in this dynamic physical world. For example, boaters warned others about trees that fell over into the river creating lethal strainers. These warnings showed us that paddlers need to update each other after their trips to keep the virtual world synchronized with the physical world.


**Figure 4.** A paddler's sketch of a critical incident in which he was temporarily pinned by an undercut rock.

### Context-Sensitive Needs Due to Flow Changes

Before deciding to run a river, paddlers need to know the difficulty of rapids at the projected level. The nature of rapids changes drastically depending on the volume of water indicating the need for putting data into context. As the flow changes, some hydraulics, known as holes, can be transformed from friendly surfing spots to deadly keepers which will recirculate an unwary paddler forever (Figure 5). The degree and pattern of recirculation for any hole indicates the level of threat. Flow changes also expose rocks that may pin a boat, drowning a paddler who flips. Other types of dangers exist (e.g., rock sieves, whirlpool eddies, and pourovers). The threat posed by each hazard depends on its shape, size, location, and the flow amount. The implication is that virtual representations need to show how flow relates to these aspects of each feature. Merely labeling hazards with icons or words would be insufficient.

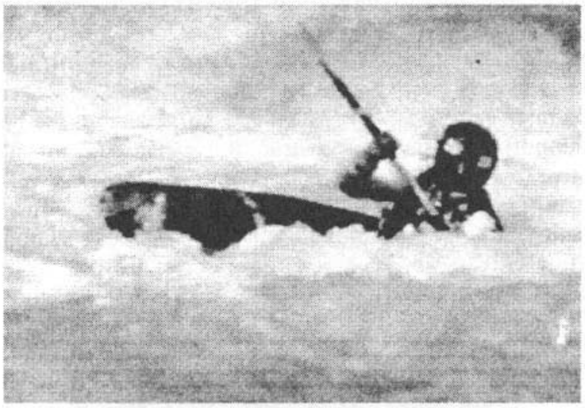

**Figure 5.** Keeper holes are one river hazard because at certain levels the recirculating flow can fatally trap a boater.

### Decision Making Challenges

As in many activities, paddlers manage risk by judging their ability, the difficulty, and the safety consequences for a particular run. Decision making dilemmas arise due to the difficulty of knowing these relative limits in an environment filled with uncertainties (e.g., gaps in knowledge, misrepresentations, or hidden obstacles). Most accidents occur when paddlers are completely surprised by hazards. They may miss hazards because their water reading skills are not sufficiently developed. In other cases, they may be misled by inaccurate or superficial descriptions of rapids. For instance, several kayakers have been fatally pinned by a small undercut rock on a seemingly innocuous rapid on the New River because this rock only becomes a hazard at low levels and is not mentioned in any guidebook. Decision making is further complicated by the fact that heuristics break down. For example, paddlers cannot always assume that a rapid becomes more difficult at greater flows. Hazards may be completely washed out at high flows. Low or intermediate flows may in fact be more dangerous. Knowing what changes mean is critical. Computers as decision aids are very well-suited to tailoring representations to changes in an environment.

### Problems Due to Over-Generalized Ratings

Boaters check gauge readings to find out river levels. However, a number from a gauge is a poor indicator of rapid difficulty. One number fails to capture what flow means. For example, in attempting to interpret 1500 cubic feet per second, a paddler must know the difficulty rating which others assign the rapid at that level (on a scale from Class I to VI). The rating assigned to the rapid generalizes over many factors, and consequently it fails to tell the entire story. A rapid rating of Class IV does not indicate the types, locations, and number of hazards. It also fails to mention the recommended lines and whether the high rating is due to technical difficulty or safety threats. Abstractions like expert ratings are useful heuristics, but decision making uncertainty is increased when their basis is hidden. Visualizations are needed that abstract out the meaning of flow changes to paddlers. The relations between expert interpretations and the physical world must be shown.

### Communication Problems and Needs

Several incidents pointed to the need for shared frames of reference and extended communication abilities. The following two examples provide some insight:

- *Underspecified instructions.* One canoeist did not adequately explain how to avoid a large hole so a novice became trapped in it. Her advice was to "go left" instead of "you need to go within ten feet of the left bank and then ferry hard across strong current which is about 100 yards wide. "
- *Ambiguous gestures.* A private rafter gestured by raising his hands in parallel. A companion assumed that meant "river clear". It really meant to follow along either bank to avoid a pourover in the middle of the river. This boater ended up in the pourover.

These two examples show the communication limitations in this physical setting. Virtual representations provide a new means for joint reference. Paddlers may more precisely specify plans to others by annotating graphics with marks or gestures and then pointing to features in the real world. Moreover, communication can be extended over a greater distance and over the noise of the rapids.

### The Main Insights from the Field Studies

The principle conclusions include the following:

- *Reading water is a knowledge-intensive skill.* It takes many years to learn how to interpret complex, noisy hydrotopography to identify safe routes and hazards. Representation aiding offers a way to speed up and improve the learning process.
- *Current representations are not context-sensitive.* Guidebooks are incomplete and inaccurate, because they generally describe rapids for an average water level.
- *Cognitive activity is distributed.* Knowledge is spread out across artifacts and people [4]. Facilitating the sharing of knowledge is a key leverage point.
- *Communication breakdowns occur.* Paddlers consult others when making decisions more than we expected . In most of the incidents, mishaps occurred due to underspecified or ambiguous instructions.

## DEVELOPING THE RAPID SCOUT CONCEPT

In our field research, we discovered many on-the-river needs. Significant opportunities existed for improving communication over people, time, and distance using computers. With a down-the-river guide, we sought to use graphic representations to provide a shared virtual frame of reference. Prototyping this Rapid Scout concept enabled us to explore issues relevant to integrating virtual and physical environments. We needed to put data into context, show relationships, highlight change and events, and draw contrasts. In creating it, we also would have to determine how multiple virtual perspectives can be coupled with the physical views to enhance and extend our senses. Representations would also have to be tailored to a specific water level to satisfy the requirement for context-sensitive information. Once we converged on these goals, we divided the design into three parts: representation, communication, and hardware aspects of the prototype.

**Virtual Representation Design**

A key goal was to facilitate the sharing of knowledge across many distributed cognitive agents both on and off the river. These agents included kayakers, canoeists, raft guides, rescue squads, and park rangers. Information needs and agent interactions were characterized based on rapid- and group-specific scenarios. Five expert paddlers familiar with the New River Gorge were consulted to identify rapid-specific scenarios and representation needs.

*Designing Views, Structure, and Transitions*

Our team, which included one kayaker, then identified possible views of the river, and compared their strengths and weaknesses. Physically-available views are often very limited (e.g., where steep canyon walls make it impossible to scout from the shore). Virtual views which are not limited by physical constraints provide new ways to expand what paddlers can see. Paddlers can be shown an overview of an entire rapid, an otherwise inaccessible side view, or overviews which show what is just around the bend. From our analysis, we chose the views that would give paddlers the most appropriate information for the selected scenarios. We avoided the garden path tendency to provide every single possible view of a rapid. Such a default approach only increases user input, navigation, and tailoring burdens.

By showing view sketches and scenario-based storyboards to users, we determined that the following views would be prototyped: a full map view of the river, half-mile overviews, a top-of-the-rapid view, a Triptik, bird's eye overviews of each rapid, and video close-ups of particularly dangerous hazards or difficult drops. In addition, we planned screens for rating personal ability, depicting the basis for rapid ratings, as well as saving and sharing annotations and stories.

In using Rapid Scout, a boater first would download or buy information about a specific river or region. Links to automated river level gauges could then be made to download flow readings to tailor the representations to the current level. Upon arriving at the river put-in, a paddler would call up the full-map view of the river. This view shows the river layout with all rapids, access points, and other geographical information. A guide's narrative with introductory video clips can also be played to learn about highlights and the most difficult rapids.

*Half-Mile and Triptik Overviews*

While paddling downstream, the user can transition to successive half-mile views (see Figure 6). At this scale, these overviews encompass flat water sections and a few of the upcoming rapids. The location of the user and other paddlers with the device is shown within the 10-meter accuracy enabled by global positioning systems. Major river features such as wave trains also become visible in these views. Virtual landmarks are highlighted that can serve as points of reference to deal with uncertain data. For instance, two rocks which form a saddle on the New River are shown as a virtual reference point for verifying river level. When the saddle is filled, the user can confirm that river is indeed over three feet. The half-mile views serve three main purposes: (a) showing what is around the bend to support anticipation; (b) tracking a paddler's location relative to friends, groups, landmarks, and rapids; as well as (c) supporting targeted communication through the selection of boater symbols (discussed in the next section).

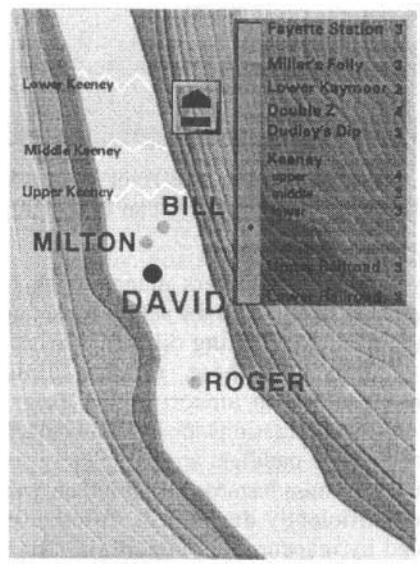


**Figure 6.** Half-mile and Triptik overview.

Two other mini-views are overlaid on the half-mile view. First, a top-of-the-rapid photo can be called up to facilitate recognition of rapids (providing another way to verify virtual-physical location). Secondly, a condensed and flattened Triptik showing the sequence of rapid names and a paddler's progress is provided on the right side of the half-mile view. Space limitations prevented the use of a full river map so we decided to provide this straightened-out view. The Triptik enables gauging the time left to complete the river. It also serves as a scrolling bar and menu providing a physical frame of reference for navigating to other views for communication and planning purposes.

*Bird's Eye Overviews*

When paddlers reach the top of a rapid, they can then switch to the bird's eye overview of that rapid (see Figure 7). It provides a big picture of a rapid's layout which is comparable to an aerial photo from 500 feet. It extends what a paddler can see in the physical world (e.g., showing the downstream side of a "blind drop"). It also shows them an undistorted layout of the rapid. In this view, we heavily use layering and separation techniques [5]. Given our exploratory prototyping approach, we separated layers of information so that we could discover useful combinations of layers (see Figure 8 for the layer model). We anticipated combining layers later on to simplify interaction.

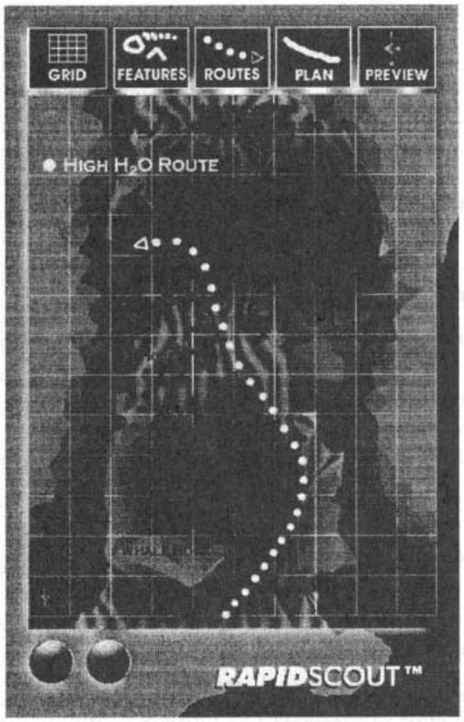


**Figure 7.** Bird's eye overview of a rapid.

Due to the importance of flow as a unifying factor, we chose to represent it in the base layer of the bird's eye view. Flow is shown in relation to other features by an animated texture map. This map is a micro-macro representation that uses tiny lines varying in length and direction to form meaningful flow patterns [5]. The patterns indicate relative sizes of features such as waves to indicate degrees of difficulty and danger. Safe limits are highlighted on the analogical representation of flow to provide meaningful alarms in context. For instance, we highlight when the a hole's recirculation turns it into a grabby keeper. Features below the surface which are hard to spot even with trained eyes are also shown on this base layer (e.g., undercut shapes of rocks). Showing these hidden features once again demonstrates how virtual representations provide unique capabilities for extending views into the physical world.

Additional layers include grid scales, recommended routes, and simulated previews (Figure 8). Video close-ups from shore side scouting locations also are available as options.. We chose to provide the recommended routes as optional layers because we maintain that users must have a basic understanding of the physical world before they are presented an expert's advice. Such an understanding allows them to better judge the validity of decision aid advice and teaches them the basis of recommendations [6]. Providing video close-ups of hazards as separate layers permitted access to more detail and different vantage points in a way that simplified navigation and reduced clutter.

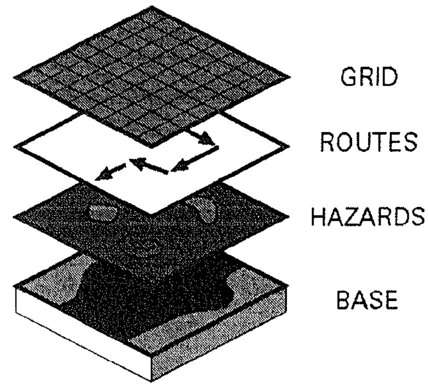


**Figure 8.** Layering of information model.

*Evaluating the Prototype in the Field and Lab*

Our river representations were evaluated iteratively at different stages using sketches, flip books, and computer prototypes. The emphasis was on discovering significant requirements (e.g., what layers should be combined) rather than on identifying minor glitches (e.g., font sizes need to be increased). We used simple as well as more functional prototypes in order to collect data early on. One such simple prototype was the laminated flip book that we used in field evaluations. The flip book included the full map, half-mile views, bird's eye overviews of two rapids, and layers which could be added to the overview (e.g., feature details, grid, and routes). Eight paddlers duct-taped these flip books to their spray skirts immediately before these two rapids to determine the usefulness of the representations in context (see Figure 9). Several insights for improving the representations were gained through this in situ testing. Ways to more accurately represent flow and the degree of hole recirculation were pointed out. Better layering schemes also became apparent leading us to combine the base water flow layer with the hazards layer.

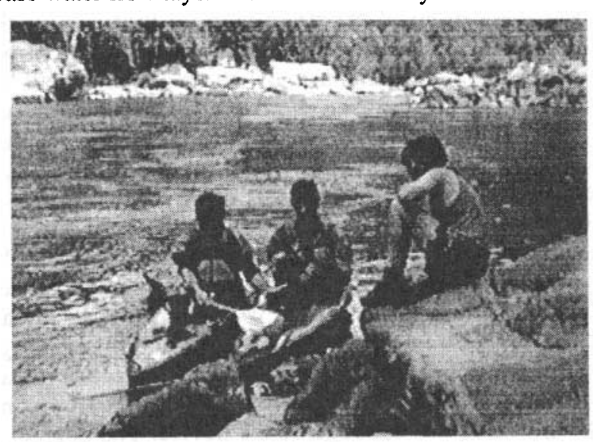

**Figure 9.** Paddlers using the flip book prototype before a rapid during the field evaluation.

We also conducted user tests with an interactive prototype. We first provided a guidebook description of a rapid [7]. Then, we asked the user to explain how to run the rapid at 3.5 feet to an experimenter who role-played a novice who was not familiar with the rapid. We then asked each subject to perform the same task for two different rapids using a dynamic computer prototype. Natural verbal protocols were collected and analyzed.

Our findings from the field and lab evaluations included:

- Tailoring the virtual representations to the particular water level greatly reduced paddler confusion. In contrast, paddlers using the guidebook had to repeatedly re-read the description to see if the advice was relevant.
- The representations captured the essence of expert descriptions though we discovered several ways to improve them (e.g., by altering the flow texture map).
- Transitions between views and layers needed to be streamlined to improve navigation between displays.
- A shared frame of reference greatly reduced ambiguity in communication. Moreover, less effort was required to direct another person's attention to specific features.

**Design for On-the-River Communication**

Drawing from the corpus of cases, we developed several on-the-river communication scenarios which we used to specify requirements, design solutions, and evaluate the prototype. Routine scenarios included an expert explaining a route to a novice before and after the expert runs it, an instructor teaching a class how to run a rapid, and a 20 person paddling club with interchanging subgroups. Non-routine scenarios which expose brittleness were also considered (e.g., when people become separated, equipment is lost, parts of the device fails, or a person is injured).

Two types of communication appeared necessary; namely, an open form and a targeted form of communication. The open form of communication is analogous to posting on newsgroups where preset groups are contacted. Whereas, the targeted communication is like e-mail which is directed to specific locations of people or groups. In designing the open communication means, many ideas came to us from our observations of the use of voice loops at NASA Mission Control. Based on their example and our requirements, we adopted a channel-based system that has two volume levels to support monitoring and talking on several channels at once. Channels being monitored are set at the lower volume to minimize distraction while still taking advantage of our divided attention ability. The scenarios helped us specify the number of channels needed and their function dedications. We included ten general-purpose channels, a "park ranger" channel, a "chatting" channel, and an option to broadcast simultaneously to all channels. Channels were monitored or talked on by pressing buttons on the edge of the device. The degree of button depression providing feedback about whether the channel was being monitored or talked on.

In addition to the channel metaphor, we allowed for targeted communication. By selecting boat symbols from the half-mile views of the river, a user could talk directly to that boater or group (see Figure 6). By directing messages to only those people for which they are intended, this means of communication promised to reduce nuisance broadcasts and improve privacy. It also provided a physical frame of reference for organizing the communication options.

Although both means of communication looked promising, we were unsure about which method would be the most useful in different circumstances. In keeping with the exploratory prototyping approach, the two communication paradigms were combined to discover in future user tests when each method is most appropriate. When combined with the graphic shared frame of reference, these open and targeted means of communication promised to extend the communication abilities of paddlers significantly.

**Hardware Design**

The most striking aspect of the hardware design process was our ability to discard prototypes when new requirements were discovered. Prototypes were used to explore the constraint space rather than to refine a single concept.

The primary consideration when exploring this space was the user's safety. Many ideas were abandoned after interviews and testing with users showed that they could become entangled on river objects or impair swimming. Some of these discarded prototypes and additional requirements included:

- A hardback screen placed in a transparent pocket on the spray skirt was rejected because it could cause the skirt to implode under heavy water pressure.
- A hardback-pullout screen housed in a drawer on the front of the kayak was dropped because it would cover the safety quick-release loop on the spray skirt.
- A flexible pull-out screen attached to the spray skirt was a success with paddlers in our usability tests, but was judged to be too futuristic.

Eventually, the requirements that we met were that the device be waterproof, shockproof, compact, light, rigid, and glare-resistant. In addition, the device could not interfere with swimming, pulling off the spray skirt, paddling, or walking. It also had to be readily accessible and easy to use in relatively calm eddies. Furthermore, we decided that equipment alterations were undesirable to keep costs down and to make it easy to rent the device from outfitters, or to share it with fellow boaters.

The latest prototype is a PDA-sized device which will be encased in a rubber coating and attached to the front of the paddler by a neoprene belt (see Figure 10). Interaction with the magnetically-sensitive touch screen is conducted using a glove with magnetized finger tips (normal electrostatic touch screens had to be ruled out because of the water). This solution satisfies the above requirements though we still view it as an exploratory tool.

Similar portable hardware already is being introduced to such sports environments (e.g., PDAs with GPS links). However, these devices generally only provide user location coordinates. In the long run, these products should aim to incorporate more functionality and information as illustrated by the Rapid Scout concept.

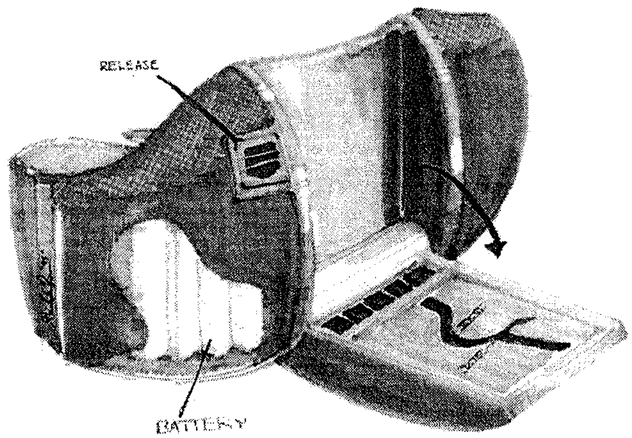


**Figure 10.** The Rapid Scout hardware.

## CONCLUSION

Rapid Scout brings together scattered knowledge and expands paddler communication abilities on the river. In designing it, we have tackled challenges including:

- abstracting out critical relationships to show people what they need to look for in the physical world (e.g., analogical representations of the degree of threat),
- providing context-sensitive information (e.g., tailoring to flow changes),
- extending user perspectives with virtually-possible views and abstractions (e.g., bird's eye overview),
- highlighting important contrasts and change (e.g., micro-macro texture map),
- indicating safety-critical limits and hidden hazards (e.g., showing degrees of recirculation),
- dealing with an unpredictable environment (e.g., providing updating, annotation, and sharing abilities),
- coordinating multiple virtual perspectives with available views in the physical world (e.g., through navigation mechanisms),
- addressing severe constraints on portable computing in this rough environment (e.g., synchronizing interaction with paddling downtimes),
- improving communication (e.g., providing a shared frame of reference and supporting collaboration over a greater distance and the noise of the rapids).

Recent advances in technology (e.g., GPS, portable computing) have provided the designer with new opportunities for bridging the gulf between physical and virtual environments. The key to harnessing the power of virtuality and ensuring that a new design will function as a useful tool is to gain an in-depth understanding through user-centered methodologies such as field investigations and exploratory prototyping.

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