NoRIS: Supporting Computational Science Activities Through Learner-Centered Design

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Abstract: Computational science provides scientists with a variety of tools and methods to help them investigate scientific problems. Computational science is becoming increasingly important, not just for scientists, but also for students who need to gain expertise with similar investigations for their scientific careers. However, because students lack the expertise of professional researchers, complexities arise that pose obstacles to students trying to use computational science to conduct scientific investigations: complexity in the number of diverse investigative tasks to perform, in the lack of tools for supporting certain activities, and in the variety of existing tools and interfaces that students have to learn. In order to address these complexities, we have used learner-centered design to guide the implementation of NoRIS, a computational tool used by nuclear engineering students investigating particle distribution problems. By using different scaffolding strategies, we found that we were able to build a tool that helps support nuclear engineering students investigating problems from their domain.

1. Introduction: Complexities for Learners Using Computational Science

Computational science provides scientists with a myriad of computational tools and methods that allow the simulation of physical processes [Defanti et al. 1990]. With the advent of more powerful computers, scientists are increasingly employing computational science tools and methods to develop insight into natural phenomena. As computational science becomes more important to scientific investigations in many domains, it is becoming increasingly important for *students* to learn the computational science tools and methods that they will use in their scientific careers [Cunningham et al. 1990].

For example, as part of their curriculum, nuclear engineering students study how shielding materials protect against the spread of radiation by using different numerical methods to computationally model the distribution of particles through different materials. By observing how nuclear engineers go about solving such particle distribution problems, we have identified areas of complexities that can pose difficulties to students trying to engage in this practice:

- *Task Complexity:* Using computational science in an investigation requires the completion of many diverse tasks. For example, nuclear engineers need to create data files, implement computer codes to represent numerical methods, plot and compare output data, etc. Students can be confused by the number of tasks that make up an investigation, making it difficult to learn how to undertake an investigation. Also, some investigative tasks are lower-level tasks that can divert the student's attention away from investigation at hand. For example, it is the researcher's responsibility to manage the different artifacts that result during an investigation, such as source codes, data files, graphs, etc. However, there is no external support for the management of these artifacts. The responsibility for the organization and access of these artifacts is with the researcher, and this "housekeeping" task can divert time, attention and energy away from the problem being investigated [Knapp 1994].

- *Tool Complexity:* A variety of tools are needed to support the different investigative tasks and to support the different learning styles of students. However, there are few tools that provide comprehensive support for the entire investigative process. For example, visualization packages are very powerful, but very specific for the visualization subtask of an investigation. Tools such as Mathematica, Maple, etc., are attempting to integrate more functionality within a single package, but these packages can be difficult for students and do not support all the investigative tasks [Springmeyer et al. 1992].

- *Interface Complexity:* Since a wide array of functionality is needed, students engaged in an investigation will need to use a variety of different tools. Therefore, students will have to learn the different tool interfaces, ranging from graphical to command-line; this can add an additional level of complexity. Students need an engaging interface that allows them to progress through a scientific investigation without the tools getting in the way.

In order to provide support (or *scaffolding*) to deal with complexities such as these, we would like to design computational tools that are aimed at non-expert *learners* who are learning a domain rather than expert *users* that simply need usable tools [Norman & Draper 1986]. Learner-centered design (LCD) is an approach that can help guide the design of such tools. Expanded discussions on LCD can be found in [Soloway et al. 1996a, Soloway et al. 1996b]. In this paper, we will describe how we began incorporating learner-centered scaffolding to develop NoRIS (*No*tebook-based *R*esearch and *I*nvestigative process *S*upport system), a computational environment for nuclear engineering students using computational science tools and methods in particle distribution investigations.

2. NoRIS: Addressing Complexity Through Learner-Centered Design

NoRIS provides a platform that enables students to engage in computational science so that they can carry out a scientific investigation. By giving learners an environment that reduces many of the complexities found in using computational science, NoRIS aims to support students as they begin learning the tools and practices of the professional researcher [see Tab. 1].

2.1 Task Complexity

Students with little expertise can be hindered by having to remember the variety of disjointed, lower-level tasks that make up an investigation. NoRIS restructures the investigative tasks into a smaller number of higher-level tasks. By streamlining the different sub-tasks into two higher-level tasks, NoRIS allows the student to begin constructing an understanding of the investigative activities that researchers perform:

- *Notekeeping:* Students need to continually record problem objectives, hypotheses, important observations, data, results, etc., throughout an investigation.

- *Building cases:* A *case* encompasses the major tasks that require computational tools, such as writing and running numerical-method programs, visualizing data, etc.

Aside from restructuring the variety of investigative tasks, NoRIS also reduces complexity by automatically supporting lower-level, managerial tasks, such as artifact management. NoRIS automatically organizes the artifacts produced throughout an investigation (e.g., notes, sources code, and data files) so that the student can focus more on their investigation and less on mundane, bookkeeping tasks.

2.2 Tool Complexity

In order to provide a single environment that students can use for scientific inquiry, NoRIS provides access to the variety of tools needed by beginning students to complete their tasks: computational tools (e.g., compilers and algebraic/mathematical software), visualization tools, etc. NoRIS acts as a type of *software bus* [Gallopoulos et al. 1994] that integrates existing software packages. Thus the student interacts with NoRIS, and NoRIS issues commands to the different software tools.

Area of Complexity	Scaffolding Strategy	NoRIS Implementation
Task Complexity	Restructure the task to reduce and manage complexity Automatic low-level task support	High-level tasks Artifact management
Tool Complexity	Provide all necessary tools in one environment Provide tools supporting different learning styles and levels of expertise	Tools for writing computational routines Notebook scheme to organize and easily access artifacts Graphical and textual visualization of output data
Interface Complexity	Initiate engagement by presenting an approachable interface Sustain engagement by: • Providing visualization to structure the task • Encouraging articulation	A simple, consistent front-end to a variety of tools Task diagrams on workspace tool Notepad button palettes structure the investigation Notepad windows for filling in notes and ideas

Table 1: Learner Scaffolding in NoRIS

For tasks such as artifact management, there are no existing tools that the student can use. Therefore, NoRIS is designed as a computer notebook, which essentially acts as a "front-end" to the computer directory structure. The notebook provides a way to easily view and access the different artifacts produced during an investigation. Also, the notebook metaphor is a familiar metaphor that is easily understood by students. For example, NoRIS include the Notebook Summary window [Fig. 1] that summarizes the different numerical-method programs that the student has written.

2.3 Interface Complexity

One of the complexities of computational science is having to learn the different computer tools and tool interfaces required for a single investigation. Because NoRIS is a single environment that acts as a front-end to a set of tools, we have designed a simple, consistent interface for NoRIS that provides button and menu-based access to the diverse set of tools. Examples include:

- *The Workspace Tool* [Fig. 2] provides button and menu-based access to the tools needed by the student to build and analyze numerical method cases. The Workspace Tool consists of buttons representing the major phases in the case-building process. The different sub-tasks for each phase are encapsulated in menus that pop-up from the different buttons in the workspace tool. The menus let students easily see and choose the appropriate task options for each phase in the case-building process.

- *The Multiplot Tool* [Fig. 3] allows the researcher to easily plot data files in the same graph window for analysis. The student can simply "check off" all of the files that they want to plot and then press the Plot button. This eases one of the most important phases of a numerical method investigation: comparing the results of different numerical methods.

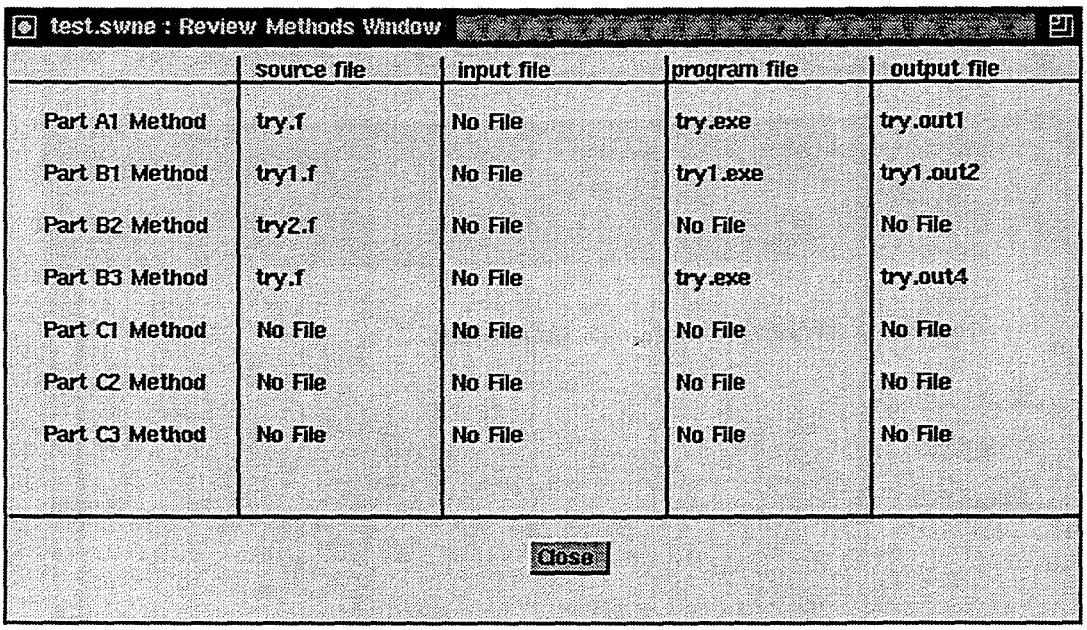

Figure 1: Notebook Summary window

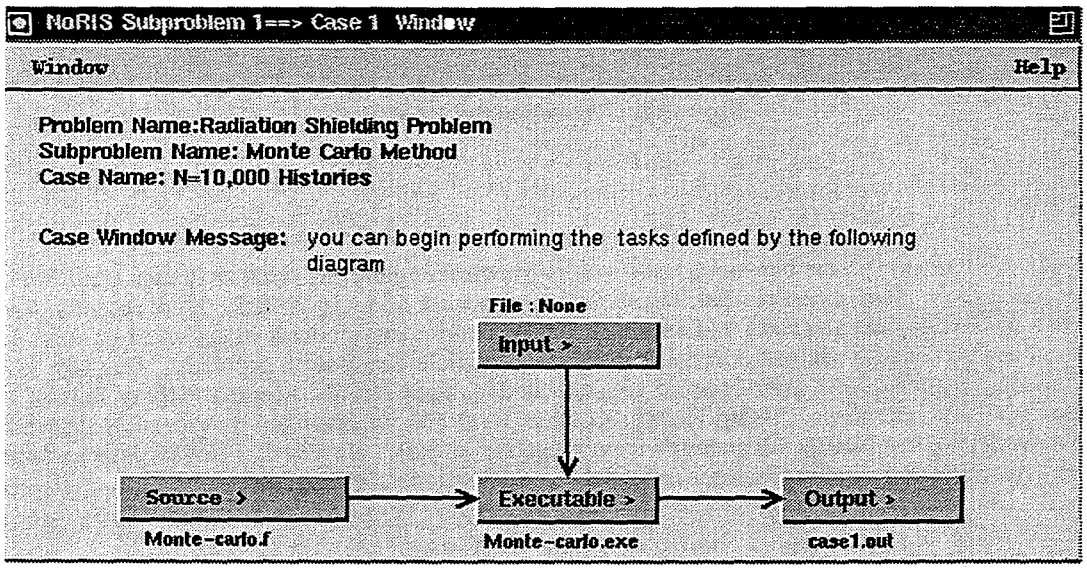

Figure 2: The Workspace Tool

The NoRIS interface not only provides simplified access to the necessary functionality, it also provides some procedural support to help the student learn the tasks that make up an investigation. NoRIS provides visual cues in the interface so that the students can identify the different tasks they must perform and the different types of information that they must record. Examples include:

- *The Workspace Tool* [Fig. 2] contains a task diagram of the process used to construct a case for the numerical method the student is investigating. As we stated earlier, each button represents a different phase in the case-building process, and each button presents the user with a menu identifying their options for that particular phase. The diagram and menus help the student to begin understanding the different tasks involved in building numerical method cases.

- *Notepad windows* [Fig. 4] contain button palettes that identify the different types of information that the student should be thinking about and recording as they work on their problem. Such information includes problem objectives, descriptions of the numerical methods they are investigating, etc. This structure encourages students to reflect and keep important notes throughout their investigation.

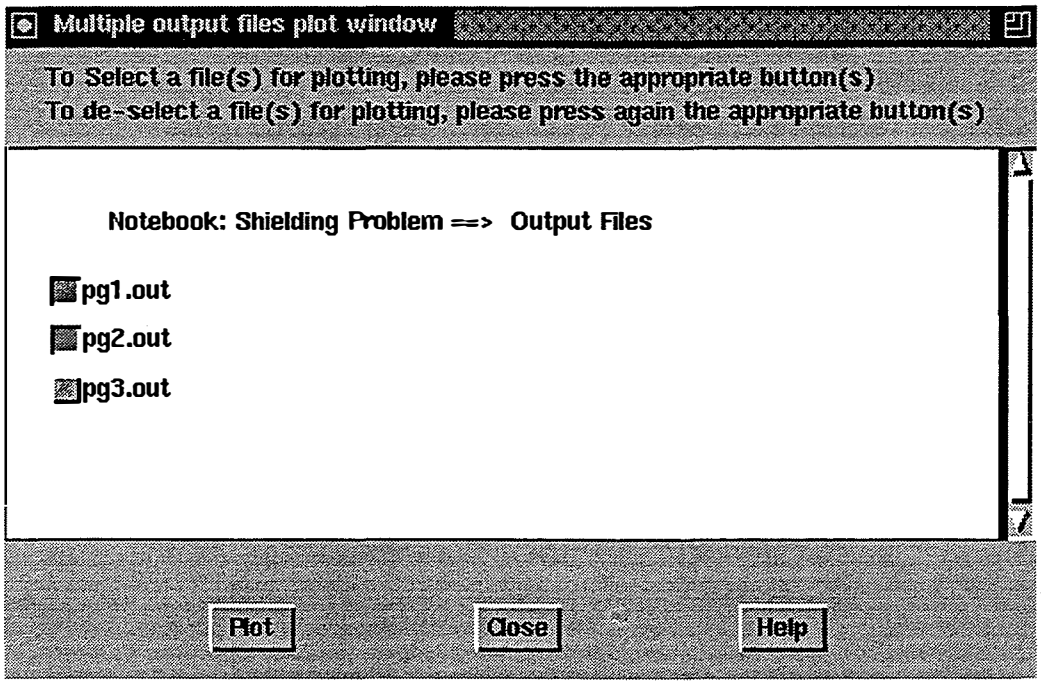

Figure 3: The Multiplot Tool

3. Results

NoRIS was initially tested in three two-week trials with two nuclear engineering students in each trial. For each trial, the students were given a particle-distribution problem to work on using NoRIS. More recently, NoRIS was used in a nuclear engineering class by five senior-level undergraduate students who worked on week-long, project-based assignments to analyze numerical methods in particle distribution problems. Our user testing included videotaping talk-aloud interviews of subjects as they used NoRIS, keeping activity logs of their actions, and post-test interviews. Using NoRIS, students were able to complete their particle-distribution assignments, verifying that NoRIS facilitates their investigative process. We saw that NoRIS gave students an environment that made computational science accessible and investigations manageable.

3.1 Task Complexity

The task decomposition and automatic artifact management used in NoRIS helped reduce the complexity of an investigation. Students quickly caught on using the Workspace Tool to set up different cases for the different numerical method trials they needed to look at in their problem. We also saw the benefits of the automatic artifact management. Since it was easy for students to find and re-use old artifacts in their notebook, students could quickly build new cases by modifying old cases. By looking at the activity logs of student actions, we saw that students would set up a base case for a given numerical method and then continually modify the base case using the functions built in the Workspace Tool. Since the time needed modify a case was small, the students began exploring different numerical methods even though their assignments did not necessarily indicate that they needed to do so.

In our post-test interviews of the test subjects, we also found that the automatic artifact management was also well liked by students because it eased the organizational tasks that can be distracting to them:

> "I am usually disorganized and after a while, I spend a lot of time organizing things– setting up directories, putting codes and things in the right places. NoRIS takes care of this; this really helps because it lets me concentrate on the problem."

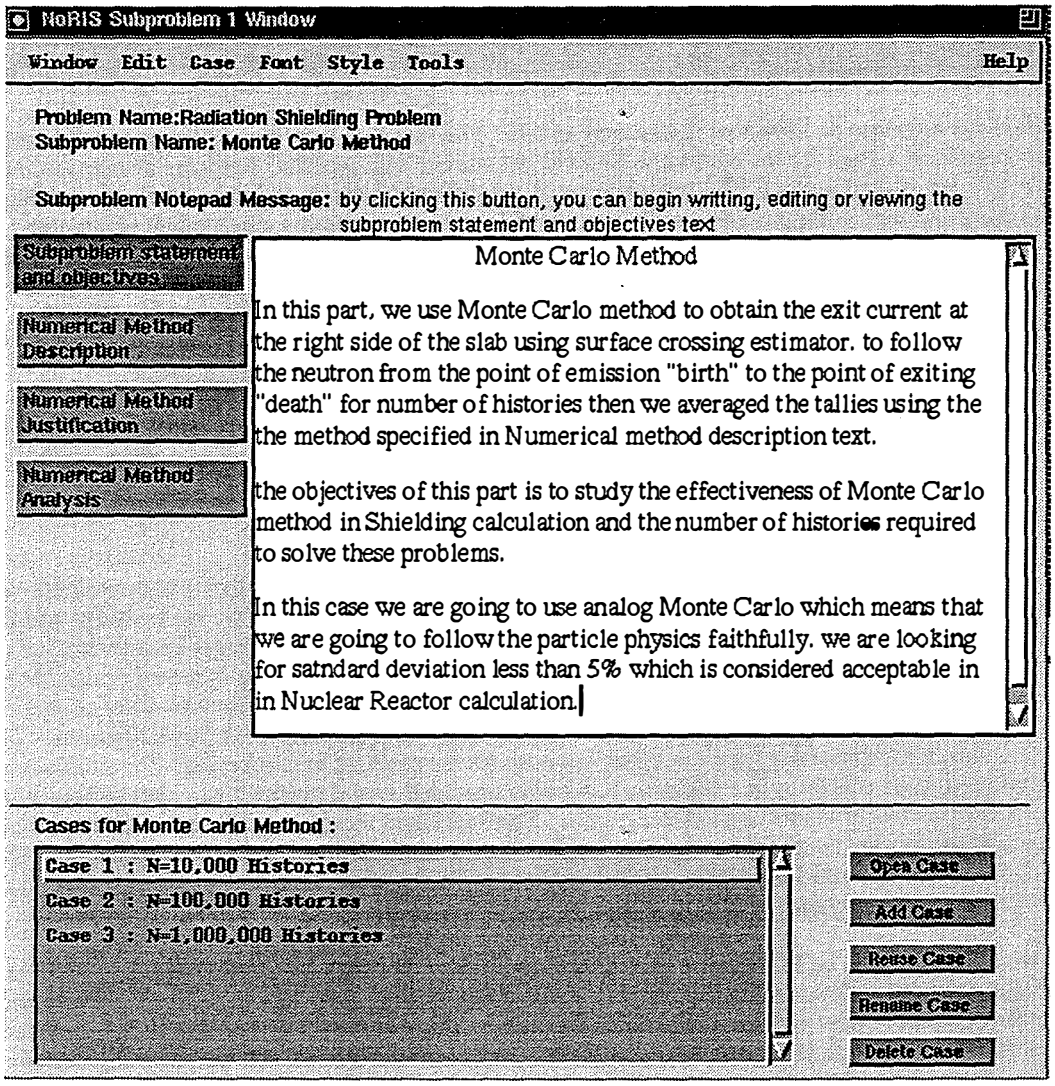

Figure 4: Notepad Window

3.2 Tool Complexity

Students liked the fact that they had all of the necessary tools available to them in one application. Since students are not experts in using computational science, they may not know what tools to use in various situations. By having all of the functionality available to them in one application, students did not have to be moving from application to application, which can be a distracting problem:

> "[NoRIS] really provides an integrated package that beginning students can really use...having all of the needed information 'at my fingertips' is an advantage so that I do not have to bounce around different programs...this is good for students who are inexperienced with [computers]"

Also, we began to see the utility of providing different types of functionality to match the different work styles of students. For example, the Workspace Tool allows students to plot output data or view the raw data. We saw that the less experienced students would plot out output data. However, some of the more experienced students preferred to look at the raw data. Since the more experienced students had a better idea about what certain numerical output should be, it was easier for them to look at the raw data. By providing both types of functionality, NoRIS allows less experienced students to use the same tool now and in the future as they gain experience and expertise.

3.3 Interface Complexity

Students liked the interface and felt that it was easy to use. The fact that they could use menus and buttons to access the tools made it easy for the student to quickly get started with NoRIS. Students also appreciated the different visual cues of the interface. The organization of the different buttons and menus helped students begin learning the tasks and terms of a particle distribution investigation. For example, one student commented on the notepad button palette that identifies the important information to record. The palette helped structure the notekeeping task and encouraged the student to articulate his thoughts:

> "[The button palette] helps lay out the thought process I should be following when I start working on my problem...Seeing [the buttons] makes me pause and think about the problem rather than just jumping in and starting to write programs, which is what I might normally do."

4. Concluding Remarks and Future Research

We have described NoRIS, a system that supports nuclear engineering students as they perform computational science activities to investigate particle distribution problems. In designing NoRIS, we have tried to address the complexities that students face as they try to engage in and understand the investigative practices of expert researchers in their field. NoRIS is a preliminary step in our investigation of learner-centered design, however, our initial results have been encouraging. NoRIS provided all the necessary computational functionality in a single environment that students were able to use successfully to complete their investigations. NoRIS provided a structure for the necessary activities that was easy for the students to understand. The simple interface was not only found to be usable by the students, but it also provided useful prompts and cues to help illustrate the range of activities that students needed to perform. Students liked the automatic artifact management that NoRIS provided through the notebook metaphor. Artifact management allowed students to spend more time on their investigation and less time on organizational chores. Also, because artifacts were easily accessed and modified, students performed more trials than they normally might have.

Currently, we are looking to build more systems like NoRIS to try to discover more scaffolding methods and design guidelines for learner-centered software. Because the NoRIS project was aimed at more intermediate levels of students, we now want to look at what kind of extra scaffolding would be necessary to support learners with less domain knowledge than the subjects in our study. We also want to look at building environments for other domains to see how we can start generalizing some of the scaffolding strategies we have looked at in projects like NoRIS.

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