High Performance Computing for High School Students: A Dam Design Competition

Kanthasamy K. Muraleetharan, Caroline A. Cochran
University of Oklahoma, Norman, Oklahoma

Abstract

High performance computing is an integral part of modern engineering design and research. Advanced computing techniques such as parallel computing are increasingly being used to solve difficult engineering problems. Many high school students are, however, unaware of these advanced computing techniques and their usage to solve real world problems. This paper discusses a pilot design competition conducted at the Westmoore high school in Oklahoma to expose high school students to advanced computing techniques and other skills in an engaging and exciting manner. A web-based, parallel, finite element computer code, TeraScale_Dysac, developed through a National Science Foundation (NSF) Information Technology Research (ITR) grant for predicting behavior of earth structures during earthquakes was used in this design competition. Students in an AP Geology class were requested to design the geometry of an earth dam to minimize the volume of earth and to satisfy the specified deformation criteria during an earthquake. The students used the full version of TeraScale_Dysac over the web, but the students were not required to vary more difficult input parameters such as the material properties and varied only the geometry of the dam.

Pre- and post-competition surveys were conducted to gather data on students' knowledge of engineering computational tools, how earth structures behave during earthquakes, and their preference for a career in science and engineering. These surveys revealed that although the competition did provide valuable knowledge for the students about engineering computational tools and the effects of earthquakes on earth structures, it had no significant influence on changing the students' career choices. The planning and implementation of this pilot design competition is presented and the difficulties encountered during the implementation are discussed and suggestions for improving a similar competition are provided. Selected survey results are also presented and discussed.

1. Overview

The dam design competition was created to expose high school students to the cutting-edge technology implemented in the finite element computer code TeraScale_Dysac. In addition to creating excitement in the students toward engineering, the project aided the traditional high school curriculum by giving team building experience and requiring higher level learning skills in the students. The web-based nature of TeraScale_Dysac has the potential to bring similar experience to remotely located high schools.

1.1 Background

TeraScale_Dysac[1] is a finite element computer code that can be used for static and dynamic analysis of two- and three-dimensional civil engineering structures made of or on soil. Soils are complex multiphase porous media consisting of a solid skeleton and number of pore fluids. TeraScale_Dysac is based on the rigorous mathematical formulation of the coupled dynamic behavior of solid skeleton and pore water and therefore enables accurate prediction of complex phenomena such as liquefaction of soils experienced during earthquakes. TeraScale_Dysac was developed through a NSF-funded Information Technology Research (ITR) project (Grant No. CMS-0112950) in a collaboration between the University of Oklahoma and the TeraScale, LLC, of Cedar Crest, New Mexico. TeraScale_Dysac uses the TeraScale's finite element framework.

A framework represents a collection of common software components for building different computer codes. The basic premise behind the use of a framework is the recognition of a common set of tasks that must be accomplished in writing any computer application code. These tasks can be factored out of the application codes and collected into a single set of components. The framework makes it easy to develop codes to take advantage of modern computational advances such as parallel and distributed computing. These modern computational techniques are absolutely essential when analyzing large 3-D problems. The dam design competition presented in this paper is part of the outreach activities of the above mentioned NSF ITR project.

What makes the TeraScale_Dysac attractive for a high school design competition is its user friendly Graphical User Interface (GUI) (see Figure 1) as well as the Application Service Provider (ASP) website and software developed by the TeraScale, LLC. The students were able to use TeraScale_Dysac by logging into the TeraScale's ASP site and running the program on TeraScale servers and then visualizing the results on their local machines.

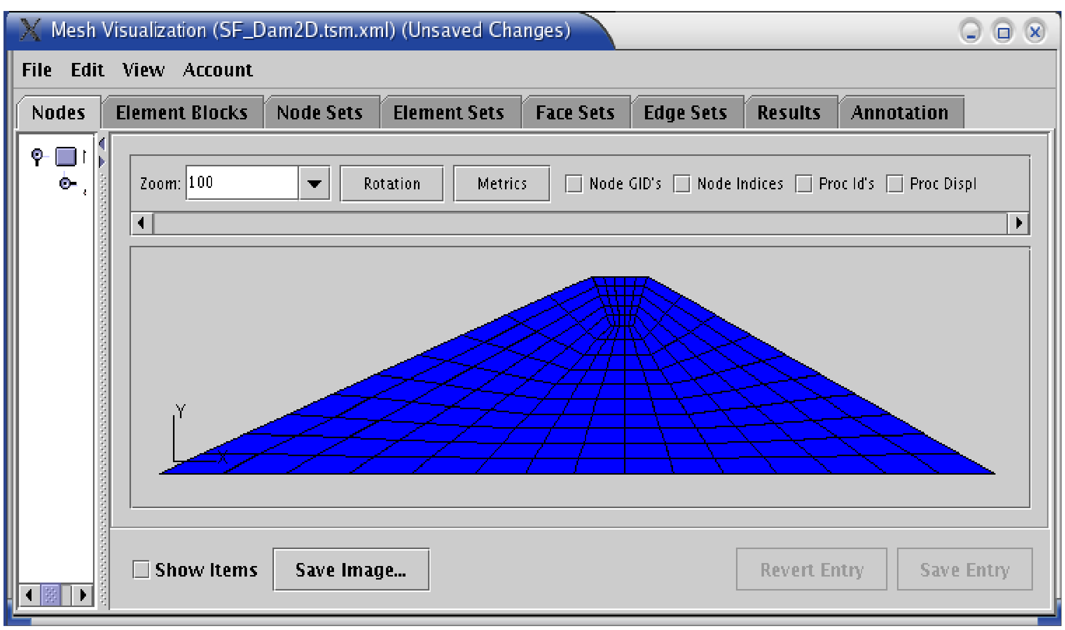

Figure 1. TeraScale_Dysac's Graphical User Interface

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1.2 Learning Skills Emphasized

In order to emphasize the relevance of a project and recruit high school teachers, it is important to tie any K-12 project to required skills published by state and local education boards. The Oklahoma Board of Education publishes a group of skills required by their students prior to high school graduation. These requirements are called PASS skills, or Priority Academic Student Skills. PASS requirements address six areas, and the dam design competition helps teachers meet standards in four of these areas.

The standards for both Instructional Technology and Technology Education are closely served by the project. Particularly, in the arena of Instructional Technology, Standard 6 states the need for "knowledge of technology problem-solving and decision-making tools."[2] Also, the Technology Education standards cover many issues addressed by the project such as optimization and trade-off concepts (Standard 2), understanding how science and mathematics enhance technology (Standard 9), exploring career opportunities through hands-on technology, computer-aided design, and engineering (Standard 20).[3]

The Mathematics and Science sections, while seemingly less directly applicable, had several standards also achieved through the project. For instance, the Mathematics section dictated that high schools should teach "connections"—linking mathematical ideas to the real world and applying mathematical problem solving to other disciplines and real-life problems (Standard 4).[4] The Science section has similar concerns of application of the concepts to real-world problems, but has the special interest of developing in students the ability to create and use models: interpreting models, making predictions based on models, and relating models to the real world.[5] The modeling and required analysis in the dam design competition develops these skills in students.

2. Dam Design Competition

The project consisted of a dam design competition given to students organized in small groups. Each group was given access to the computer program TeraScale_Dysac through TeraScale's ASP site. The program was explained through presentations given during two class periods and through handouts. The students were then encouraged to correspond with us through email. A deadline was given for the design along with a cash prize for the first and second places.

2.1 Development

We decided that a competition, along with prizes for incentives, would be the best way to expose students to TeraScale_Dysac and the associated learning skills. A competition, in theory, brings an element of excitement which would hopefully be carried over to the subject and engineering in general.

TeraScale_Dysac has many facets, and despite its clean, user-friendly interface, could be complicated even for a knowledgeable engineer. So, for the competition, the number of parameters to optimize had to be limited. The material for the students' dam was a single given soil. In addition, the height of the dam was given as a constant. The geometry of the dam could be varied, and the students were given a template to begin their design with. The goal of the design was a dam cross-section with minimal area that could withstand a given earthquake loading without settling lower than 1 meter below the crest. Having a minimal cross-sectional area means the dam design requires the least amount of material and would create the most economical dam; a very realistic design problem. The description of the competition provided to the students is given in Appendix A.

2.2 Implementation

To pilot test the dam design competition, we choose a teacher (Mr. Brad Brauser), who was very willing and had a history of encouraging interesting science projects to his class, and his AP Geology class from the Westmoore high school in Oklahoma. There were 19 students in the class. We visited the school twice. The first visit was used to introduce the topics of earthquakes and finite element analysis. A handout of the presentation was given to the students. The second visit took place in the school's computer lab (see Figure 2) and was used to explain TeraScale_Dysac as well as the competition. Handouts with important instructions for the program and for the rules of the competition were handed out during this visit.

Figure 2: Describing the Competition to the Students in the High School Computer Lab

After these presentations, instructions were given to the teacher to organize the students into ability-distributed teams of three to four students. Then the students were on their own to complete the project with the incentives of $200 for the first place design and $100 for the second place design. The project was not counted for a grade in their class.

The project was planned to take advantage of the program's capability to be run and taught remotely. However, the high school did not allow the necessary GUI interface program to be installed on its computers. The Westmoore school district is a big school district and according to the local computer administrator, the required permission to install software on local machines would have taken over a year. This forced us to require the students to use their computers at home. In addition, some students became fearful of security concerns in installing the GUI interface program on their home computers because of a warning that the program will read files off the computer. The GUI interface program was issuing this warning because it needed to transmit TeraScale_Dysac files between a local machine and the TeraScale's ASP site. So the original plan was modified to invite the students to the university computer lab. Instead of resolving questions by email, most of the interaction was face-to-face. A picture taken in the university computer lab during a help session with the students is shown in Figure 3.

Figure 3: Working with the Students in the University Computer Lab

The difficulties in program accessibility may have led to an initial frustration for the students while others had problems making it to the university lab. Many were graduating seniors or had time constraints such that a voluntary project did not interest them even with the cash prize. The end result was that we allowed students to reorganize their teams. Although most of the teams started the competition only one of the teams completed the project and submitted the final report. This team, however, did an excellent job and came up with a design that required only 1.59 million m^3 of clay for a crest settlement of 0.997 m. Note that the base design provided to the students required 1.9 million m^3 of clay and had a crest settlement of 0.880 m.

3. Evaluations

The importance of evaluating an educational project is well recognized by all educational researchers. We considered the following objectives in creating the pre- and post-competition surveys.

- Encourage interest in science and engineering careers,
- Basic understanding of soil behavior during earthquakes,
- Basic understanding of computing capability and limitations to model and predict this behavior,
- Increased understanding or a simple introduction to finite element method concepts such as nodes, elements, and meshes,
- Increased understanding or a simple introduction to the mathematics and physics concepts of stress and strain.

3.1 Structure of Evaluations

The following questions were included on both the initial and final surveys.

Are you interested in a career related to science and engineering?
The question was followed by "No" and "Yes" checkboxes and lines for "If so, are you interested in a particular career? Please list career(s)."

Do you know what will happen to an earth dam during an earthquake?

This question was likewise followed by “No” and “Yes” checkboxes, and if yes, lines were provided for explanation.

Can computers be used to accurately predict how an earth dam will behave in an earthquake? This question had boxes similar to the one above

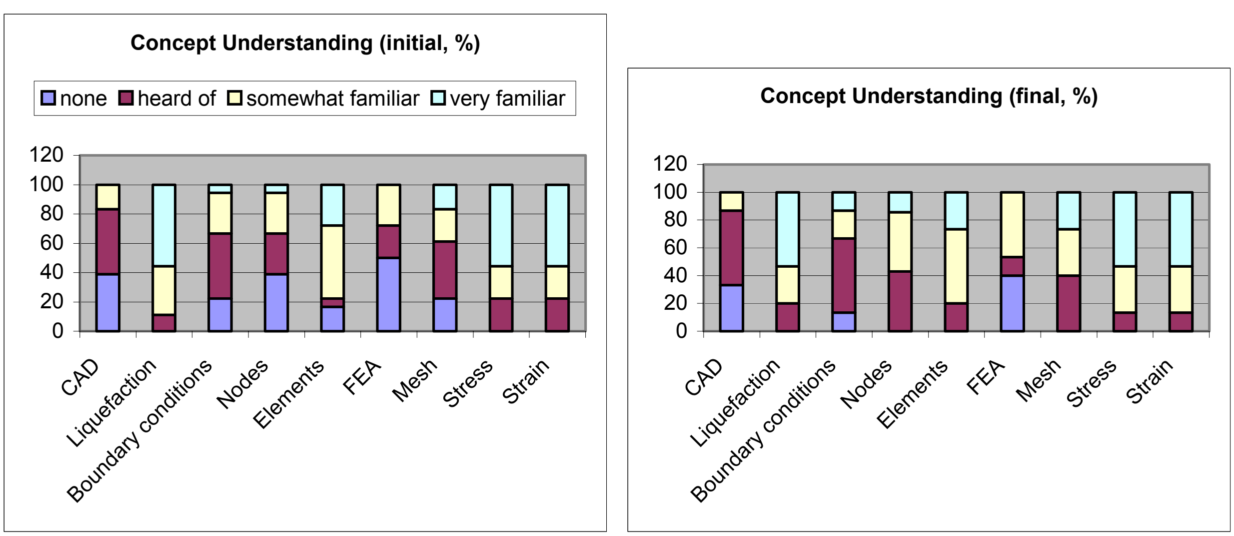
Lastly, a series of checkboxes were provided beside selected terms for students to indicate whether their experience with the terms was “None,” “Heard of,” “Used once or twice (somewhat familiar),” or “Used many times (very familiar).” The list of terms included *CAD*, *Liquefaction*, *Boundary conditions*, *Nodes*, *Elements*, *Finite Element Analysis*, *Mesh*, *Stress*, and *Strain*.

The initial survey also had questions for the students to indicate whether they had studied earthquakes before and whether they had used a computer to model or analyze something before. The final survey had additional questions of whether the students completed the project, what the finite element method is, and room for comments on the dam design competition and suggestions for improvement.

3.2 Selected Results from Evaluations

The small pilot class means that evaluations will not give statistically significant results, but give only general indications. The questions with space for responses carried especially varied answers. Overall, the competition was found to have provided valuable knowledge for the students about engineering computational tools and the effects of earthquakes on earth structures. However, the evaluations showed that the competition did not have any significant influence on the students’ career choices.

The responses in percentage to the familiarity of terms are shown in Figures 4. As can be seen, the familiarity level increased for all the terms after the competition.



(a) (b)

Figure 4. Students Responses to Familiarity of Terms (a) Before and (b) After the Competition

4. Lessons Learned

The evaluations showed the dam design competition to be valuable, but there are many factors that could and should be changed should the project or similar be executed elsewhere. First listed below are aspects that the experience showed should be taken in consideration. Next, a list of suggestions is given to address these considerations and improve the project.

4.1 Considerations

Below are issues encountered during the dam design competition:

- *Students not very technologically savvy*

Surprisingly, although most high school students are highly computer literate by their senior year, they may not be very flexible to use other interfaces and programs than those they are familiar with.

- *Need for willing/enthusiastic teacher*

The dam design competition was fortunate to find an exceptionally enthusiastic teacher, which was a huge contributor to the success of the project. This is a key for any similar project.

- *Remote instruction fostered confusion*

Despite having a dedicated and enthusiastic teacher, students did not contact us until late after problems surfaced. The lack of one-on-one interaction exacerbated their frustration and led to the entire class' unfounded security fears before we were able to respond to these concerns.

- *High school would not allow installation of the program*

This was a critical problem since we could not have a hands-on session at the high school for all the students. Only few dedicated students showed up at the university lab. Also, without school lab facilities the students had the additional constraint of having to meet after school at their homes to work on the project.

- *Email may not be a good mode of communication for high school students*

This is a lesser consideration, but an important one. Part of the reason the students did not contact us is that most of them did not regularly use email, did not have their own computer, and had limited access to the family computer, or, especially, limited access to the internet. This may be used as a positive aspect, by additionally using the project to encourage the use of this tool among students. However, this should be taken into consideration for any remote instruction situation.

4.2 Improvements

Possible improvements are as follows:

- *Better communication to offset remote instruction difficulties*

After it was apparent that the class had installation difficulties and security concerns, we went to the high school to answer questions in person and to get an email/phone list. This list should be obtained during the first visit, and regular emails should be sent out to encourage questions before problems escalate and cause frustration. All of this should take place also with the consideration that email may not be ideal for communicating with high school students.

- *High school program accessibility*

Better foresight and groundwork should be done to ensure that the students have alternatives to home computers. Most likely any high school would have the same obstacles to installation of new programs. However, instead of only inviting students to the university lab after problems surfaced, that option should be open to the students from the beginning.

- *Better training for students and teacher*

The teacher suggested an instructional video be used. This is a good suggestion. The video should include screen captures of setting up and running the program. In addition, a detailed step-by-step user instruction and a list of common mistakes made by students will help.

- *Using PASS skills to sell the project*

Although we were able to find a willing teacher and a classroom for the pilot project, many projects could use similar standards to those listed in Section 1.2 to entice teachers to host the projects. Many state standards are adapted from national standards and are similar to those given in Section 1.2

5. Conclusions

All university outreach programs are important to providing much needed curriculum supplementation for Grades K-12. As shown through the evaluations, the students enjoyed the project and gained knowledge of engineering computational tools and concepts that they would not have otherwise. It is hoped that the considerations and improvements provided in this paper assists other projects to benefit K-12 students.

6. Acknowledgements

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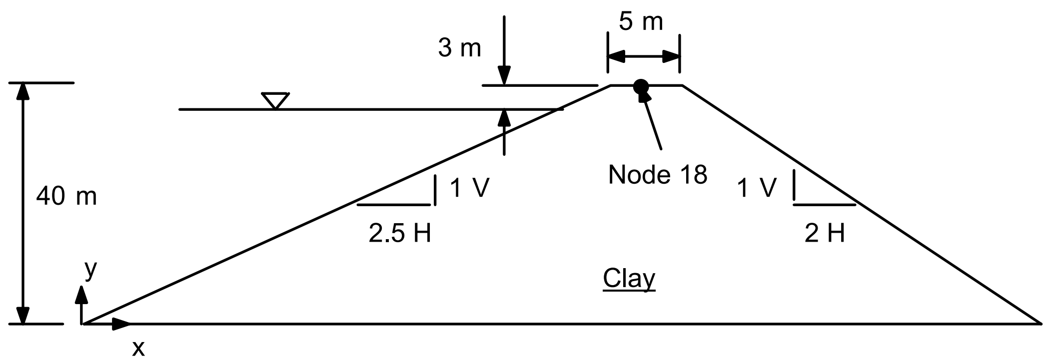
Appendix A

Westmoore High School Dam Design Competition: Spring 2004

Sponsors:

K.K. (Muralee) Muraleetharan
Associate Professor
School of Civil Engineering and Environmental Science
University of Oklahoma
&
TeraScale, LLC
Cedar Crest, New Mexico
(www.terascale.net)



Calculated cross-sectional area, A = 3800 m^2
Length of the dam, L = 500 m
Volume of clay = A x L = 1.9 million m^3

A cross-section of a dam similar to the Lower San Fernando Dam is shown in the above given figure. The spillway is about 3 m below the crest. You are to design the dam to restrict the downward movement (displacement) of the crest to no more than 1 m for the given design earthquake (see the file wmh_dam0.xml*). The height of the dam has to remain at 40 m and you also have to maintain the width of the crest at 5 m. The maximum downward movement of the crest for the given cross-section is 0.88 m and therefore the dam can be redesigned more economically.*

Each group should submit a short (5 pages maximum including the cover page) report including the following by May 18, 2004 to Mr. Brauser.

1) Introduction
2) Sketch of the final cross-section, the maximum downward movement of the crest, the calculated area of the cross-section, and the volume of required clay.

3) Sketches of the cross-sections tried, the maximum downward movement values for the crest, cross-sectional areas, and a brief description of how the final cross-section was chosen.
4) A paragraph on how dams behave during earthquakes.

First Prize = $200 – for the group with the lowest volume
Second Prize = $100 – for the group with the next lowest volume

Notes:

1. The Lower San Fernando Dam nearly failed during the 1971 San Fernando Earthquake (M = 6.6).

2. In your TeraScale Application Service Provider (ASP) accounts each group will be provided with the following three files necessary to analyze the given cross-section using the computer code **TeraScale_Dysac**: *wmh_dam0-recipe.xml, wmh_dam0.tsm.xml, and wmh_dam0.xml.*

3. If you keep the shape of the dam essentially the same, creating the finite element mesh will be simple and you can use the mesh recipe already provided to you with very little modifications. If you want to try an innovative shape, however, meshing the dam will be challenging. You will also have to find a new node number on the crest to obtain the vertical displacement-time history of the crest. Don't let this hold you back. If you think you can come up with a better shape, go for it. *Hey! $200 ought to be worth something*.

4. If you need help, contact Caroline Cochran through email at *Caroline7c@aol.com* with cc to *muralee@ou.edu*.

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2. "PASS: Instructional Technology", *School Improvement*. p.423. Adapted with permission from *National Educational Technology Standards for Students: Connecting Curriculum and Technology*, copyright 2000, International Society for Technology in Education. Online: http://www.sde.state.ok.us

3. "PASS: Technology Education", *School Improvement*. p 425-427. Online: http://www.sde.state.ok.us

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Biographies

K.K. (MURALEE) MURALEETHARAN is an Associate Professor in the School of Civil Engineering and Environmental Science at the University of Oklahoma. His research interests center on geotechnical earthquake engineering. His educational interests include mobile computing, freshmen education, and alternative learning paradigms. He received the University of Oklahoma Regents' Award for Superior Teaching in 2000.

CAROLINE COCHRAN is an honors Mechanical Engineering and Economics senior at the University of Oklahoma. Her activities include the Formula SAE race team, the Spirit V solar car team, and functioning as the University of Oklahoma Student Association's Communications Coordinator.