Editors: Gitta Domik
and Scott Owen

Integrating User Studies into Computer Graphics-Related Courses

Beatriz Sousa Santos, Paulo Dias, Samuel Silva, Carlos Ferreira, and Joaquim Madeira
University of Aveiro

Computer graphics and visualization are essentially about producing images for a target audience, be it the millions watching a new CG-animated movie or the small group of researchers trying to gain insight into the large amount of numerical data resulting from a scientific experiment. To ascertain the final images' effectiveness for their intended audience or the designed visualizations' accuracy and expressiveness, formal user studies are often essential. In human-computer interaction (HCI), such user studies play a similar fundamental role in evaluating the usability and applicability of interaction methods and metaphors for the various devices and software systems we use.

Computer scientists and engineers working in these areas must thus be able to design and conduct user studies to test and evaluate the performance of not only new algorithms and methods but also complex hardware and software systems. That involves applying the stages of the traditional scientific method, such as observation, hypothesis formulation, verification through data analysis, and reproducibility. Moreover, the pervasive use of computers as tools for interdisciplinary research also demands a strong foundation in the scientific method.[1]

The IEEE Computer Society and ACM Joint Taskforce on Computing Curricula recognizes the scientific method's importance and considers it a base methodology for much of the computing discipline.[2] Also, several authors have identified skills in using empirical methods as critical for computer graduates and have proposed ways to promote them in study programs.[3–5]

Here, we show how we've successfully introduced students in CG, HCI, and information visualization courses to empirical methods through designing and performing user studies.

User Studies

User studies are a particularly challenging type of empirical method owing not only to human cognitive and perceptual systems' complexity and variability, but also to the ethical issues involved. User studies aim primarily to seek insight to guide future efforts to improve existing techniques, methods, or products (for instance, understanding why a particular technique is effective). Such studies might also aim to show that a theory applies under certain practical conditions.[6] So, addressing user studies is of great interest in CG, HCI, and information visualization courses.

In the studies we've performed with our classes, our students have collaborated as experiment designers (advanced students), experimenters, or merely subjects (younger students). This has helped our students acquire some of the skills required for performing empirical studies. These skills range from conducting a well-defined user study and comparing the obtained results with the anticipated ones (at the introductory level), to formulating hypotheses and designing user studies to test them (at an advanced level). These skills are similar to those that Grant Braught and his colleagues identified as being expected of all computer science graduates.[3]

Over four years, we performed two sets of user studies in which students from four CG and HCI courses collaborated in different roles. One set involved experiments addressing the perceived quality of meshes simplified through different methods; the other compared the usability of a virtual environment (VE) in different setups. Although we designed our experiments for pedagogical purposes, we carried them out in the scope of actual university research. So, our approach introduces students to empirical methods and research in general.

In addition, in an information visualization course, we recently developed and tested a protocol for comparing the effectiveness of two tree visualization techniques.

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The Perceived Quality of Simplified Meshes

Polygonal meshes have a range of applications but are often too complex to process in a reasonable amount of time. A mesh model's complexity is usually reduced through a simplification method, producing a perceptually similar mesh with fewer vertices and faces.

Although several such methods exist, only a few user studies have investigated the simplified meshes' perceived quality. It's not yet clear how the simplification method and level influence the resulting model's perceived quality. Similar issues occur regarding other mesh-processing methods such as smoothing. Although mesh quality indices are a lower-cost alternative to user studies, it's unclear how they relate to perceived quality or which indices best describe user behavior.

We carried out several user studies as part of ongoing related research that evaluated polygonal meshes' perceived quality while looking for a quality index that estimates user performance. We considered our CG students' participation in these studies as an adequate introduction to empirical methods, and their participation would increase the user studies' statistical relevance. So, we asked for their volunteer collaboration in lab classes after we had addressed polygonal-mesh modeling in lectures.

In a lab class, we briefly presented the research context, the main experiment's goals, and the protocol. We provided the minimum information necessary for student participation, to avoid creating a bias due to too much information. Once all the students had participated and we analyzed the collected data, we further explained our goals, experimental design, and the results in a lecture. We also posted a document providing additional details on the course webpage. We repeated this procedure with a slightly different protocol in two consecutive years. Further details on these studies appear elsewhere.[7,8]

Usability in VR

Emerging desktop-based VR applications are available in new application areas, and the average PC now has a powerful graphics card that lets it provide desktop VR. However, usability is key for VR to reach its full potential. Guidelines and background information about the added value or appropriateness of alternative solutions are fundamental to successfully use VR products.

Of particular interest are differences in user performance and navigation (a core VR task) that might result from different ways of interacting with the VE and various environmental characteristics. Such characteristics include those of different displays and interaction devices (as on a desktop) or of immersive displays such as head-mounted displays (HMDs). With the former, users employ an abstract interface (for example, a mouse and keyboard); with the latter, users map their physical changes of direction directly in the VE.

We performed several user studies as part of an ongoing study comparing user performance in a VE using different setups. The first study took place in our HCI course in the context of an MSc thesis comparing performance using a desktop and an HMD. Each student participated individually after hearing a short explanation of what he or she was expected to do. The students had already attended a lecture about controlled experiments as a method for user interface evaluation, and we explained the experiment's goals and design after the data was collected. We also posted a document explaining the experiment on the course webpage.

Most students were motivated by their participation in this user study. This convinced us that it was a more effective way to teach the advantages and difficulties of controlled experiments in general (and user studies in particular) than just addressing the subject in a lecture.

So, we continued this study the following year. We asked a group of four more-advanced students to design and conduct a user study as their final practical assignment. The VE and task were the same as in the original study, but we introduced a third setup that projected the image on an ordinary screen. As planning for the experiment continued, we devoted a few minutes in class each week to debrief all the students concerning the experiment's main issues.

Although we advised the four students how to select a hypothesis and the experimental design, we didn't really help them with the complex logistics involved in the experiment (for example, selecting and contacting the users, looking for an adequate location, installing the equipment, and running the experiment). They performed the experiment with 18 users during an afternoon; we invited all the students in the course to observe the study. Later, the four students presented their main findings; with their help, we wrote a paper that we presented at an international VR conference.[9]

We were nicely surprised with this activity's outcome. We believe that all our HCI students (not just the four who designed and implemented the study) had a better understanding of empirical methods after these studies, which made the issues of VEs and 3D interfaces more real. You can read more about these studies elsewhere.[9,10]

Information Visualization Evaluation

Workshops and discussion groups have discussed evaluating information visualization techniques, and we believe that MSc-level information visualization courses must also address evaluation. So, we recently introduced a user study as a practical activity in such a course. We invited the student who had submitted the best practical assignment, which involved implementation and improvement of a tree visualization technique, to design a user study to evaluate the improvements.

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The student had chosen this technique because he was interested in using it professionally. So, unlike the other studies we've described, this one had practical implications, not just research implications. We advised the student on the experiment's design and discussed the protocol in class with all the students who had participated in the pilot trial. This helped us improve the study's protocol so that the student could test it on a sample of participants he had selected as representing prospective users.

Considerations and Results

Given our user studies' dual purpose—to introduce students to empirical methods and comply with real needs—we had to consider several issues before applying a particular experiment in a specific course, with a particular group of students. For example, we had to consider what type of experiment would be appropriate for a specific type of course (subject and level), how much class time to allocate, and how the experiment might impact a class.

Although students often participate in real studies, student participation is often considered a hindrance to obtaining valid results. Yet, student participation can be sufficient in exploratory studies to validate protocols or whenever students aren't expected to differ from (a relevant part of) the target population. So, results obtained from student participants are useful and can complement results from other participants.

It's also important to have an adviser on statistical methods, to both analyze the collected data and help develop the protocol so that the study's results aren't compromised owing to poor design.

We didn't include a formal introduction to empirical methods or user studies in our CG course syllabi. However, we believe that students gain much valuable experience when they participate in real user studies and actual research using empirical methods, such as the study on polygonal meshes' perceived quality.

On the other hand, HCI courses usually address empirical methods. However, this topic is complex and difficult to explain to younger students. So, we organized user studies around user interface evaluation because we were convinced that participating in a specific controlled experiment would foster a better understanding of the topic. This confidence came from having run such experiments as a complement to our courses for several years.

Yet, we had never formally assessed the students' perceived value of participating in the user studies. To determine this, we had 49 students who participated in the user study in the last edition of our introductory HCI class take a brief survey. In the survey, the participants used a Likert-type scale (1 = completely disagree, 5 = completely agree) to evaluate three statements:

- Participating in a specific experiment promotes a better understanding of controlled experiments.
- Attending the results presentation session helped me better understand the controlled experiments.
- Participating in a specific controlled experiment is a positive aspect of the HCI course.

The results supported our theory. The median values of the replies to the statements were 4, 4, and 5. Nobody completely disagreed with any statement. Most of the 49 students gave the first statement a rating of 4 or 5, and all of the students said they liked participating in the experiment. Of the 49 students, 22 had attended the results presentation session; three students gave a rating of 5, 12 students gave a rating of 4, six students gave a rating of 3, and one student gave a rating of 2. For the third statement, no one gave a rating of 2, 21 students gave a rating of 4, 26 students gave a rating of 5, and two students gave the third statement a rating of 3.

On the basis of our experience and our students' positive feedback, we assert that incorporating user studies in CG, HCI, and information visualization courses is a positive approach to

teaching empirical methods. Yet, it implies careful consideration of several issues before performing a user study in a specific course and with a particular group of students. We plan to continue including user studies in our courses whenever we have ongoing research needs that fit the curriculum and student level.

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Beatriz Sousa Santos *is an associate professor in the University of Aveiro's Department of Electronics, Telecommunication, and Informatics and a researcher at the Institute of Electronics and Telematics Engineering of Aveiro. Contact her at bss@det.ua.pt.*

Paulo Dias *is an assistant professor in the University of Aveiro's Department of Electronics, Telecommunication, and Informatics and a researcher at the Institute of Electronics and Telematics Engineering of Aveiro. Contact him at paulo.dias@ua.pt.*

Samuel Silva *is a computer engineering PhD student in the University of Aveiro's Department of Electronics, Telecommunication, and Informatics and at the Institute of Electronics and Telematics Engineering of Aveiro. Contact him at sss@ua.pt.*

Carlos Ferreira *is an associate professor in the University of Aveiro's Department of Economics, Management, and Industrial Engineering and a researcher at the University of Lisbon's Operations Research Center. Contact him at carlosf@ua.pt.*

Joaquim Madeira *is an assistant professor in the University of Aveiro's Department of Electronics, Telecommunication, and Informatics and a researcher at the Institute of Electronics and Telematics Engineering of Aveiro. Contact him at jmadeira@ua.pt.*

Contact department editors Gitta Domik at domik@uni-paderborn.de and Scott Owen at sowen@gsu.edu.