Introducing students to empirical methods in CG and HCI courses through user studies

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Abstract

Empirical methods are increasingly important in the computing profession. Computer scientists and engineers must be capable of designing and conducting experiments in order to test and evaluate new methods and complex systems. Moreover, the pervasive use of computers as tools for interdisciplinary research also demands a strong foundation in the scientific method. Yet, traditional curricula do not devote much attention to this issue and, until recently, almost no effort has been made towards explicitly identifying empirical concepts and skills needed by computer scientists/engineers, and developing methods to integrate them into the standard curriculum.

In this paper an argument is made for introducing the use of empirical methods into courses in the areas of Computer Graphics and Human-Computer Interaction. Two suites of user studies that have been developed and performed for three years, with the collaboration of students from different courses at various levels, either as experiment designers (advanced students), experimenters or merely participants (younger students), are described. These experiments have also been used to promote an earlier introduction to research as advocated in the scope of the Bologna process.

Categories and Subject Descriptors (according to ACM CCS): K.3.2 [Computers and Education]: Computer and Information Science Education—I.3.0 [Computer Graphics]: General—

1. Introduction

Empirical methods are increasingly recognized as important in the computing profession. Computer scientists and engineers must be able to design and conduct experiments in order to test, and evaluate not only new algorithms and methods, but also complex hardware and software systems. Even though the typical Computer Science approach is quite dissimilar from experimentation, as it is known in other sciences, the fact that the Computer Science subject of inquiry is not matter or energy but information does not preclude the application of the traditional scientific method (i.e., based observations, hypothesis testing, and reproducibility). Indeed, according to Newell and Simon, Computer Science is the study of the phenomena surrounding computers and a scientific enterprise in the usual meaning of the term: it develops scientific hypotheses which it then seeks to verify by empirical inquiry [NS76]. Moreover, there are many cases in which experimental procedures have lead to interesting research results in computer science [Tic98] [Fei09] [Fei07], and the pervasive use of computers as tools for interdisciplinary research also demands a strong foundation in the scientific method [RBC*02].

Yet, traditional curricula do not devote much attention to empirical methods and, until recently, almost no effort has been made towards explicitly identifying empirical concepts and skills needed by computer scientists/engineers, and in developing methods to integrate them into the standard curriculum [BMR04]. However, there is an increased awareness concerning the need to address such issues, and some authors have been trying to identify the core empirical concepts and skills for computer science [BMR04], as well as proposing methods to integrate them into courses on such different subjects as programming languages [BR02] [Bra05], com-

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puter architecture [Bem02], or human-computer interaction [Cla98] [Mil03].

In this paper, we briefly justify the importance of introducing computer science/engineering students to the subject of empirical methods, and describe how we have been achieving it, for some years, in Computer Graphics and Human-Computer Interaction courses through particular experiments (user studies) carried out with the collaboration of students.

One set of experiments addressed the issue of perceived quality of polygonal meshes simplified using different methods. Another is meant to compare the usability of a Virtual Environment in different platforms. Advanced students have been collaborating as experiment designers, experimenters, or participants, while younger students collaborate as experimenters or participants.

These experiments were not organized merely for pedagogical purposes as they were carried out in the scope of actual research work in progress at our University. Thus, students are not only introduced to empirical methods and research issues, they also actively participate in research work, as promoted in the scope of the Bologna process. In fact, and according to the Dublin descriptors, qualifications that signify completion of the 2nd cycle are awarded to students who "have demonstrated knowledge and understanding [...] that provides a basis or opportunity for originality in developing and/or applying ideas, often within a research context" [Bol05].

2. Empirical methods in Computing curricula

As put by Tichy [Tic98], computer professionals must observe phenomena, formulate explanations, and test them (i.e., use the scientific method) in order to understand information processes. Actually, the questions faced by computer scientists are often empirical in nature, requiring more than just theoretical analysis. Many of the most meaningful real-world claims in computer science depend on the evaluator's ability to conduct valid experiments and analyze their results.

The importance of the scientific method in education is recognized in Computing Curricula as representing a basis methodology for much of the discipline of Computing [JIA01]. While recommending that students should be exposed to the scientific method, this document does not provide guidance as to which empirical concepts are important or how they can be integrated into the Computer Science curriculum. Moreover, several authors have identified skills in using the scientific method as critical for computer graduates and have proposed ways of promoting them in study programmes; examples can be found in [Cla98] [Mil03] [BMR04] [BZ07]. Braught, Miller and Reed [BMR04] also propose a list of competencies that should be expected of all graduates in Computer Science, including empirical concepts that must be understood, as well as skills that are required for experimental studies. In addition, they identify skills at different levels, ranging from the ability to (1) conduct a well-defined experiment, and compare obtained results with the expected ones (introductory level), (2) design a test suite for a software project and conduct systematic debugging (intermediate level) and, finally, (3) apply experimental methods to the analysis of complex systems in different domains, as well as to formulate hypotheses and design experiments for testing them (advanced level). According to the same authors, such skills should be fostered at different courses along a study program: students should first learn fundamental concepts and perform well-defined experiments, and later revisit those concepts, progressively building upon past experiences to gain more advanced skills, such as the capacity to design their own experiments.

In agreement to these ideas, we have been assigning different roles in our experiments to students according to their course level. Thus, students in introductory courses participate as subjects or experimenters, carrying out a previously planned experiment, while advanced and more interested students may design their own experiment.

3. Two suites of user studies to introduce empirical methods in CG and HCI courses

User studies are a particularly challenging type of empirical method due not only to the complexity and variability of the human cognitive and perceptual systems, but also since specific ethical issues are involved. While Computer Graphics and Human-Computer Interaction deal with techniques and methods, and create products to be used or perceived by humans, user studies are often essential to evaluate and validate them.

Another (more) fundamental goal of conducting user studies is to seek insight in order to guide future efforts to improve existing techniques, methods or products (e.g., understanding why a particular technique is effective). Yet another use for such studies is to ascertain whether some hypothesis is verified under certain practical conditions [KHI*03].

Therefore, addressing user studies is of multiple interest in CG and HCI courses. For this reason we have been introducing, for several years now, the use of empirical methods into courses in those areas offered at different levels, through user studies. As already mentioned, these studies were not designed specifically to meet pedagogical goals (introduce students to empirical methods and promote early contact with research), they also must comply with research needs.

This duality of purpose implies taking several issues into consideration before carrying out an experiment in a particular course and with a specific group of students. These issues are related to pondering which experiment is more adequate

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to which type of course (CG, HCI, introductory, advanced), the amount of class time that should be allocated to the experiment, which role students should play, what, how and when information should be given to which students, how should students be rewarded by their participation, etc.

In the following sections we will briefly present two suites of user studies performed for three years with the collaboration of students of four different courses in CG and HCI, describing their research context and why we assigned them to specific courses and students.

3.1. Perceived quality of simplified polygonal meshes

Polygonal meshes have a wide range of applications, and several methods for building and processing them have been proposed [BPK*08]. However, meshes are often too complex and need to be simplified in order to make feasible their processing. The complexity of a polygonal mesh model is usually reduced by applying a simplification method, resulting in a similar mesh having less vertices and faces. Although several such methods have been developed, only a few observer studies are reported comparing them regarding the perceived quality of the obtained simplified meshes, and it is not yet clear how simplification method and level influence the quality of the resulting model, as perceived by the final users. Similar issues occur regarding other mesh processing methods such as smoothing. Mesh quality indices are the obvious less costly alternative to user studies, but it is also not clear how they relate to perceived quality, and which indices best describe the users behaviour.

Some user studies were performed as part of on going work related with the evaluation of perceived quality of polygonal meshes, while looking for a quality index which estimates user performance. On the one hand, we considered student participation in these studies as an adequate activity to introduce students attending our Computer Graphics course to the use of empirical methods. On the other hand, their participation would increase the statistical relevance of our user studies. Thus, we asked for their volunteer collaboration, during lab classes, after the subject of polygonal mesh modelling had been addressed in lectures.

In these classes the research context, the main experiment goals, as well as the protocol were briefly presented, providing the minimum information necessary to allow the students to participate in the experiment, and avoiding offering too much information as not to bias them. Later on, after all the students had participated and the collected data were analysed, a more complete explanation of the goal, experimental design and obtained results was given in a lecture. Also, a document was posted on the course web-page, so that anyone interested in additional details could read it. This procedure was repeated with a slightly different protocol, in three consecutive years. Details of each user study can be found in [SFMSS06] [SSSFM07] [SSSMF08].

3.2. Usability in Virtual Reality: Comparing setups

With the development of new technologies, Virtual Reality (VR) is entering new application areas. Moreover, VR does not necessarily mean immersive stereoscopic visualization: many emerging VR applications are desktop based and not stereoscopic. In addition, almost any PC has now a powerful graphics card allowing it to act as a desktop VR instance.

Although usability studies are necessary for VR to reach its full potential, and despite the overall growing interest, few usability tests and evaluations have been reported. Moreover, guidelines and background information about the added value or appropriateness of alternative solutions are fundamental for the implementation of VR products.

There is much interest within the field of Virtual Environments (VEs) on how different forms of interaction and a variety of environmental characteristics may affect navigation (a core task in VEs). For instance, differences in user performance might be due to the use of different displays and interaction devices, such as in a desktop setup or when using an immersive display (such as a Head Mounted Display - HMD). With the former a person uses an abstract interface (e.g., mouse and keyboard), but with the latter the person's physical changes of direction are directly mapped in the VE. Several user studies were performed as part of an on-going usability study comparing user performance in a VE using different setups. The first user study was performed in the scope of a MSc. thesis and compared user performance in a setup using a Head Mounted Display (HMD) to a desktop. We asked students of a Human-Computer Interaction course for their collaboration as participants in their free time.

Each student participated individually (since we only had one HMD) and received a very short explanation of what he/she was expected to do. Students had already attended a lecture about controlled experiments, which is one of the methods used for user interface evaluation, and a full explanation of the goals and experimental design of the experiment was given after the data collection was complete. In this case, we also posted a document on the course web page. A description of this user study and its main results can be found in [SSDP*08].

Most students found the participation in this experiment as motivating, and we were convinced 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. As a consequence, we decided to continue this study during the following year, and asked a group of four (more advanced) students to design and conduct another user study as their final practical assignment.

In this later study, while the Virtual Environment and task were maintained, a third setup (where the image was projected on an ordinary projection screen) was introduced. As the experiment planning proceeded, a few minutes in class

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were devoted every week to debrief all the students concerning the main issues that were under consideration. The experiment (involving 18 users) was performed during one afternoon, and all the course students were invited to come by and observe for a while. Later, the four students who designed and implemented the experiment, made a presentation of their main findings and a paper was written with their help, and submitted to an international conference on Virtual Reality. Details about this experiment can be found in [SSDS*08].

It is important to notice that, while the four students were advised to a reasonable extent on the hypothesis selection and experimental design by the educators, they did not have as much help on the complex logistics involved in the experiment (e.g., selecting and contacting the users, looking for an adequate location, installing the equipment and running the experiment).

Once again we were positively surprised with the outcome of this activity. In fact, we believe that it contributed to a better understanding of empirical methods by all the students attending the course (not only the four who had designed and implemented the experiment), and made the issues of Virtual Environments and 3D interfaces more real. As a consequence we decided to keep on performing such experiments.

In the following semester the same experiment using the three setups was carried out again, with a new protocol adapted to investigate the possible effect on user performance of a few secondary variables that had previously been identified as potentially relevant (such as user training with the HMD). This third user study was performed in the scope of another MSc. thesis, with the collaboration of Human-Computer Interaction students of that semester as participants and following the same steps as the first study, concerning the way students collaborated and were debriefed, before and after the experiment.

3.3. Discussion

A formal introduction to empirical methods is not included in the syllabus of the courses on Computer Graphics we offer, as it is the case in the Human-Computer Interaction courses.

Nevertheless, we believe that the opportunity to participate in real user studies, integrated in actual research work, such as the ones concerning polygonal mesh perceived quality, was a valuable experience to our students. This is not only due to the general interest of empirical methods, but also given that Computer Graphics deals with techniques, methods and systems, which produce images meant to be perceived by humans, and thus user studies are a very useful method in their evaluation and validation.

In Human-Computer Interaction courses, empirical methods are usually addressed in the scope of user interface evaluation. Another issue that had to be considered in all cases was whether students should be rewarded for their collaboration in the experiments, and how it should be done. Although users that participate in usability tests performed in industry are usually paid for their time, since students had collaborated in an academic context, we felt this would not be necessary. However, some type of compensation should be given, apart from the expression of our gratitude, and we decided to offer some refreshments to all participants.

4. Conclusion

We described how we have been using user studies in Computer Graphics and Human-Computer Interaction courses with a twofold purpose: (1) introducing students to empirical methods, and simultaneously (2) promoting contact with real on-going research work.

We contend that this approach is generally positive. Nonetheless, it implies a careful consideration of several issues before using it in a specific course and with a particular group of students. These are related to pondering, among other issues, (1) which experiment is more adequate to which course type (subject and level), (2) the impact the experiment should have in classes, (3) which role students should play, and (4) what, how and when should information be given.

As a word of conclusion, we state that we will go on performing this type of activity with our students, whenever we have on-going research work needs that fit the purpose of the courses we offer, and are adequate to the students' levels and capacities.

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