Project-Based Learning of Advanced Computer Graphics and Interaction

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Abstract

This paper presents an educational case study and its pedagogical lessons. It is a project-based course in advanced computer graphics and interaction, DH2413, conducted in the fall of 2012 at the Royal Institute of Technology (KTH), Stockholm, Sweden. The students and the teacher, the author, learned through a constructivist approach. The students defined and researched the material covered in class through their theme selection of original research projects which consisted of interactive graphics systems. The students demonstrated, taught, and discussed with each other what they had learned. Finally, the students openly presented their work to hundreds of people in large public venues. The teacher's role was to design the learning environment, guide the research, provide in-depth lectures on the research material chosen by the students, and organize and motivate the students to produce accountable results. In synthesis, the pedagogical lessons are: 1) learning means building with self-motivation, guidance, and accountability; 2) self-motivation means trust and independence; 3) guidance means asking for less, not more; and 4) accountability means public presentations of working systems.

Categories and Subject Descriptors (according to ACM CCS): K.3.2 [Computers and Education]: Computer and Information Science Education—Computer science education;

1. Introduction

In a traditional setting, the teacher defines and delivers the material of the class, promotes skill building through hands-on projects, and tests the students' competence of the material through tests. This traditional format is best suited for introductory classes, where many experts agree on the content. Most introductory courses in computer graphics aim at delivering the core material and producing the foundational skills that focus on basic modeling, lighting, rendering, and animation techniques. In this context, most domain experts largely agree on the material that an introductory class should present. On the other hand, computer graphics as a field has advanced in widely diverging directions. Advanced courses in computer graphics do not share the equivalent large overlap of core material. The choice of content depends more on the context and goals of individual classes. Flowing with this trend, the course's teacher encouraged the students to fully direct the choice of material for the class. The primary goal of this choice, and the main pedagogical lesson from this experience, was the building of a trust structure for supporting high levels of self-motivation among the students.

The paper presents: 1) a summary of the course's methodological structure situated within its foundational pedagogical framework; 2) a summary of the student projects; 3) a synthesis of the core pedagogical lessons; 4) practical take away points for using information and communication technologies in 2012 for managing a project-based course; and 5) a synthesis of the testimonials from students, professors, and general audience members who interacted with the resulting projects.

2. Course Structure and Framework

The course was an instance of a constructivist learning framework, similar to project-based learning and learning by design [KC03, T00]. Constructivism proposes that deep procedural knowledge can be obtained only by the experience of building the artifact of the focus of learning. Students learn about aerodynamics by building cars that use less energy to move by reducing drag forces on the body of the vehicle.

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They learn to design and anticipate results by needing to understand the theoretical framework of the problem. They remain motivated and engaged by the inherent properties of the challenge, building a faster car, and not by the theoretical underpinning of the material, Navier-Stokes equations. The goal is not to memorize the theory, lexical knowledge, but to learn to use the theory to solve engaging problems, procedural knowledge, the hallmark of engineering.

The course is the third and last in a sequence of graphics and interaction classes. The first in the sequence, Introduction to Visualization and Computer Graphics, DH2320, has the pre-requisite of basic programming and mathematics. It introduces concepts like geometrical transformations, illumination models, removal of hidden surfaces and rendering and introduces the fundamental principles of interaction programming. The second course, Computer Graphics and Interaction, DH2323, increases the breadth and depth of the programming and theoretical computer science prerequisites. Ideally, students complete the introductory course first. The Advanced Graphics and Interaction course, DH2413 and the topic of this paper, has Computer Graphics and Interaction as a prerequisite. Ideally, the students who enroll in this class have followed this sequence. In practice, most of the students in the class had followed an equivalent sequence. It is important to note that they were all capable programmers at the beginning of the course, and many understood advanced computer graphics content from DH2323.

The class consisted of 15 two-hour lectures from August 27 to December 12, 2012 delivered in the Visualization Studio, an advanced graphics, interaction, and visualization laboratory at KTH. The goal of the physical and technological context was to motivate the students to produce technology that would be integrated to the operation of the lab and to facilitate the use of current technology under the expert support of the laboratory personnel.

Structurally, the course included an introduction, two overview lectures of advanced computer graphics and human computer interaction techniques, a series of teacher-led lectures with material based on the themes chosen for the class projects, and a number of student presentations focused on the advancement, discussion, and presentation of the projects detailed below.

In the introduction, the teacher described the course structure to the students and negotiated the most successful approach to engage the students in independent research and learning. The teacher encouraged the students to use the class as a launching platform to produce a portfolio of their skills through their choice of projects. The argument was to build tangible evidence that future employers will search for and to target the type of job the students would like to be doing five years into their future. In a follow up one-on-one thirty-minute interview with each student, all the students explicitly stated understanding, appreciating, and using the class as an opportunity to build their portfolios.

The overview lectures had the purpose to motivate the students to build exciting projects by presenting the state of the art in industry and at conferences like ACM SIGGRAPH and CHI. The teacher-led lectures based on material from projects aimed at deepening and broadening the lexical knowledge necessary for project advancement. The lectures also included in-class, hands-on, programming exercises to develop the building blocks of the procedural knowledge necessary to complete the projects.

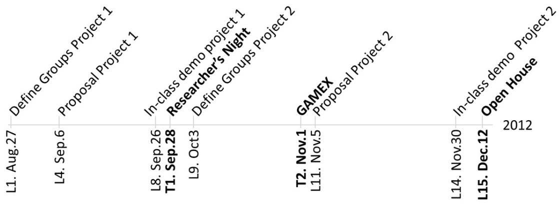

Figure 1: *A timeline of each project's four milestones: group formation, project proposal, in-class demonstration, and public presentation. L stands for lecture and T for public Talk.*

The course asked for mid-term and final group projects. Figure 1 presents a timeline of each project's four milestones: group formation, project proposal, in-class demonstration, and public presentation. Each project required the students to combine at least one advanced computer graphics technique with one advanced interaction technique. There were ten master students who grouped into three mid-term projects and four final projects. Each group consisted of three or four students, except for one of the final projects with a single student. Each project consisted of: 1) a proposal and weekly updates; 2) a technical presentation with a demo; 3) public presentations and hands-on demonstrations of the project results with interaction with the audience; and 4) a written project report.

The students had one week to produce the proposal. Their tasks were to perform a literature review of the area of their choice, determine the boundary of the state-of-the-art, and identify future original research that would push this boundary. The teacher guided the choice of areas at every step. For their proposals, each group presented a project goal, a literature review, a work schedule, and a detailed description of the techniques aimed for the project. Other students provided critical feedback focusing on the feasibility, novelty, and value of the project. The teacher moderated the discussions and provided concluding remarks urging the groups to focus on one main goal per project.

The students had three weeks to complete the projects. The students presented short weekly updates to other members of the class. The teacher and other students provided pointers to potential solutions to challenges faced during the execution of the projects. The project in-class presentations included a hands-on demonstration, an oral presentation of the material learned to the rest of the class, and a critical discussion questioning and defending design choices.

The course provided project accountability by replacing individual, written, and private examinations with group, verbal, and public presentations where students demonstrated their expertise through knowledgeable explanations and justifications of project design choices. The students publicly presented their mid-term projects in three venues and their final projects in one. The first venue was a national education convention, Researcher's Night (Forskar Fredag), where all major universities presented their research to over 5,000 high school students and teachers during a day-long event at a large public library and exhibition venue, Medborgarhuset (civic hall) in Stockholm. The goal of the convention was to disseminate state-of-the art research and match the interest of the students with the educational focus of potentially recruiting universities. The three projects generated one of the highest throughputs in the convention, with hands-on interactions and discussions with hundreds of attendees. The teacher instructed the students on practical interview techniques to collect constructive feedback from audience members. The students treated the audience as formative user study participants. The teacher covered the fundamental semi-structured interview and participant observation techniques to the students before their presentations.

The second presentation venue was a major international gaming fair, GAMEX, held at the city's convention center, Kistamässan between November first and fourth. The event drew a crowd of over 25,000 attendees. The students took turns to present for four ten-hour days. They interacted with hundreds of participants. Local technology-centered reporters interviewed the students, the teacher, the visualization laboratory's director, and gamers who interacted with the students' project demonstrations. Once again, the students interacted with hundreds of attendees, some of whom were professional 3D modelers and game programmers.

The third and final presentation venue was a class Open House held at the Visualization Studio where the students presented their mid-term and final projects to KTH professors, researchers, other students, and general guests. Below, we provide testimonials of the public's reception of the projects.

Finally, the written project reports expanded on the proposal documents. The reports included a project goal, a review of related work, a methodological section, results, participant feedback and conclusions and directions for future work based on participant feedback. Below, we provide a summary of these reports.

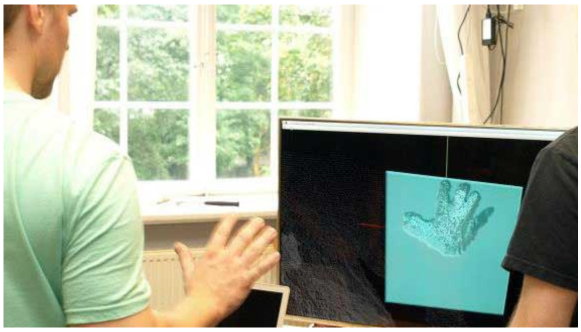

Figure 2: *User interacting with Virtual Sculpting.*

3. Project Summaries

3.1. Virtual Sculpting

The Virtual Sculpting project combined real-time volume rendering with computer vision to create an experience of sculpting in the air with your hands (see Figure 2 and Video Figure 1). Users stand in front of a screen and interact with a Microsoft Kinect. The screen combines a virtual 3D model and the 3D model of the user. Through an Play Station controller, the user can rotate the model or the point of view of the model. The user carves the model by subtracting voxels from the volume by intersecting their 3D shape with the 3D volume.

3.2. Dust Storm

Figure 3: *User interacting with Dust Storm.*

The Dust Storm project combined real-time particle systems simulating wind, gravity, and density with gesture-based interaction through the wii mote (see Figure 3 and Video Figure 1). The group created a railed-shooter game where the object of the game is to destroy opponent turrets on a desert planet as the railed cannon is passing by the standing opponents. The player loses by allowing too many turrets to survive.

Figure 4: *Users interacting with Planetary Defence on three different platforms: a laptop, a desktop computer connected to a large display, and a smart phone.*

3.3. Planetary Defence

The Planetary Defence project combined online rendering with WebGL, html 5, and three.js with multi-platform, multi-player interaction through webSockets (see Figure 4 and Video Figure 1). The object of the game is to survive a planetary attack from neighboring planets. Each player owns a planet from which rockets are launched to neighboring planets. The players can defend their planet by firing rockets at the incoming rockets or by clicking/taping on them. With a mouse, players shoot rockets with a click and draw operation. On a touch screen device, players shoot rockets with a flick.

3.4. Warbots

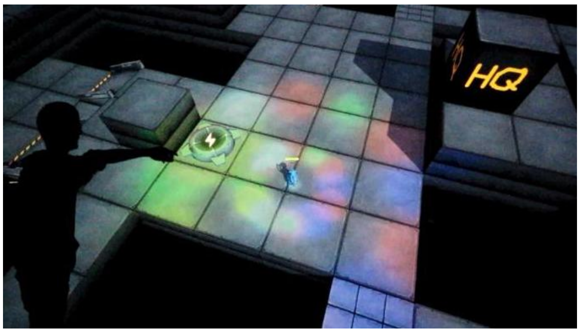

Figure 5: *Student explaining deferred rendering in Warbots.*

The Warbots project combined deferred rendering for real-time multipoint light source generation and multiplayer interaction (see Figure 5 and Video Figure 1). Warbots is a group tactics game where the object of play is the conquest of the opposing team'sheadquarters. Each team is composed of three robots with specialized roles that must collaborate to win the game.

3.5. Base Jumper

Figure 6: *User interacting with Base Jumper in front of a large screen.*

The Base Jumper project combines real-time large landscape rendering, snow particles, gravity and aerodynamics modeling with computer vision control of a wing suit computed with a Microsoft Kinect (see Figure 6 and Video Figure 1). It is an immersive experience of gliding through snow covered mountains on a winged jumpsuit rendering on a four-meter 4K screen in the visualization laboratory.

3.6. Zombie Apocalypse

Figure 7: *User interacting with Zombie Apocalypse in front of a large screen.*

The Zombie Apocalypse project explores a single point directional light source and x-box control for an immersive experience of surviving a zombie attack in a winter forest (see Figure 7 and Video Figure 1). It also explores real-time large-scale landscape rendering, fog, and tree model generation.

3.7. Android Air Battle

The project Android Air Battle combines multiplayer smartphone control of an airplane with a single, large-screen shared view of the airfield battle and it explores real-time cloud rendering (see Figure 8 and Video Figure 1). Each player controls one airplane with by tilting their smartphone as a steering wheel and shooting by pressing on screen buttons. A single large screen renders the volumetric clouds, the

Figure 8: *Screen shot of Android Air Battle.*

position, direction, and speed of individual airplanes, and the combined actions of the players.

4. Pedagogical Lessons

In synthesis, the pedagogical lessons are: 1) learning means building with self-motivation, guidance, and accountability; 2) self-motivation means trust and independence; 3) guidance means asking for less, not more; and 4) accountability means public presentations of working systems.

As stated above, the course is an instance of a constructivist learning environment. The goal is to facilitate procedural learning for the students by providing ample opportunities to create projects. Nevertheless, simply asking for projects and giving the students time to complete the projects is not enough. First, students must be self-motivated to complete the projects. Each project typically requires hundreds, if not thousands, of human hours in developing, testing, and evaluating. To engage students in a process as arduous as this, the rewards must be proportional to the efforts. To create a structure of rewards, traditional classes rely mostly on the grading system. The course provided binary grades for completing the stages of the projects. The teacher did not want to compare projects based on their grades. When completed, all projects were worth P for passing grade (versus F for incomplete projects). Therefore, the rewards and motivation structure needed to be built on a different foundation.

The course promoted self-motivation through a foundation of student independence and mutual trust. First, the teacher deposited complete trust in the students by encouraging them to propose fully independent projects. The only unmovable requirement was to combine one advanced interaction technique with one advanced computer graphics method. Second, the teacher explicitly made clear that the students could and should use the class as an opportunity to build professional portfolios highlighting the skills they would want to be hired for. Third, the students learned to trust each other and the teacher by participating in an open and honest forum where ideas could be built and polished together through constructive criticism.

Creating working systems that combine at least one advanced computer graphics technique with one advanced interaction method in three weeks among three students is not a simple task. Guidance is paramount. The teacher and the other projects' students provided constant guidance by continuously focusing the goals of the proposed projects. At every stage of the class, student groups continued to propose to add more features into their projects. The teacher's main guidance role, surprisingly, was not to ask the students to do more. In fact, and in order to have completed projects that could be publicly presented, the teacher's role was to encourage the students to remove features from their designs and razor focus on the one main graphics and one main interaction techniques being explored. The guidance paid off in outstandingly working demonstrations and mountains of positive user feedback.

Finally, as stated by the students themselves, the greatest motivation to build outstanding projects were the public presentations. Having to face audiences of hundreds of users meant having robust, stable, engaging, visually stunning, interactively immersive projects. Personally and as a group, all the students stated having worked more on this class than any other class in their careers. More impressive, they all stated doing it out of voluntary will. They felt internally compelled to excel and their projects demonstrating extraordinary commitment to perfection. In 16 years of university experience, 12 as an instructor, the teacher had never seen this level of commitment and self-motivation from every member of the class. Public accountability played a major role in focusing the students efforts and in maintaining their self-motivation.

5. Practical Lessons

The teacher used many information and communication technologies to guide, coordinate, motivate, and engage the students outside of the 30 hours in the classroom. Namely, the class relied on, in order of importance, a Facebook group, a shared Dropbox, Skype communication, Doodle scheduling, cell phone calls and sms, email communication, and the class official website. The coordination of the three large public presentations took significant effort. The class spent several face-to-face hours coordinating. Early in the semester, it became clear that coordinating in class time would consume the entire period. The class partially offloaded the task of coordinating and sharing links, documents, and comments, to the wall of its Facebook group. The class used the Facebook wall in class to share comments and links during the lecture as well. It became a practical method for collaborative sharing resources that could be projected on the wall (see Figure 9).

A number of students who could not physically attend class for various reasons opted for using Skype to call in and watch, listen, and participate in the class discussions. Attendance was never mandatory. It was up the teacher to

Figure 9: *The Visualization Studio at KTH as a studio-based learning environment.*

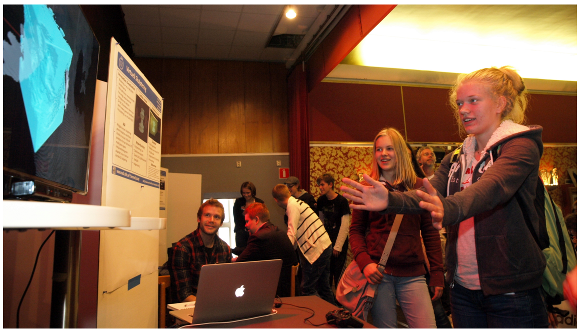

Figure 10: *Audience members at Researcher's Night interacting with Virtual Sculpting.*

keep class interesting and up to the students to participate. Everyone made a significant effort to participate physically or remotely. Interestingly, traditional email and class website were inconsequent. Not unexpectedly, using cell phone calls and sms became a major coordination tool for last-minute event planning. The teacher shared cell phone numbers with the students on the first weeks of class. A take away point in this section is the extraordinary need for online coordination and collaboration tools to offload the burden on class time. In a future instance of this course, the teacher will engage the students online earlier and more actively and reserve the class periods for relevant learning material.

6. Testimonials

All the students in the class expressed pride in their work. All but one had publicly presented original research for the first time in their lives during this class. The high school students at the first venue treated the course's students as rock stars. Identifying with their peers just a few years ahead in education and witnessing the exquisite skills and depth of knowledge they had acquired, fired the imagination of the teenagers and they were very vocal about it (see Figure 10). The high school teachers deeply congratulated the students on their work. The gamers at the conference couldn't stop playing the games. The professional 3D modelers stated that with Virtual Sculpting they could build drafts of models in seconds that would takes hours using traditional tools. Media reporters made a big story of the class, the students, and their projects. A senior professor stated that he had been advocating for 50 years to get a class like this into his university. All the students stated that they had never worked harder or more motivated in any class in their academic careers.

7. Conclusion

This paper presented a case study of problem-based learning in advanced graphics and interaction. The subject matter and the learning environment provided a motivational platform that culminated in the completion of seven projects for ten students. The pedagogical synthesis of the case study is: 1) learning means building with self-motivation, guidance, and accountability; 2) self-motivation means trust and independence; 3) guidance means asking for less, not more; and 4) accountability means public presentations of working systems.

8. Acknowledgements

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