AC 2011-2730: A GUIDED INQUIRY-BASED LEARNING APPROACH TO HIGH PERFORMANCE COMPUTER GRAPHICS EDUCATION

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A Guided Inquiry-Based Learning Approach to High Performance Computer Graphics Education

Introduction

Computer graphics (CG) is among the most quickly developing areas of computer science and it is applied in its traditional fields such as scientific visualization, gaming, and computer aided design. Recently, with the development of advanced CG hardware (Graphics Processing Unit – GPU), a new area has emerged and CG has also found its way into high-performance computing. GPUs are used as extremely powerful numerical coprocessors and they assist in many scientific areas such as genomics, nanophysics simulations, biology, astrophysics, and computational fluid dynamics, among others.

However, grand challenges exist to integrate GPU-oriented high-performance computing into undergraduate and graduate education. In order to learn parallel programming and computational thinking, it is necessary to development new curricula, strategies for conveying these concepts, and appropriate formative and cumulative mechanisms for instructors and the learners. One of the initial steps for the development of new curricula is a clear notion of the "enduring understandings" that learners should adopt from any learning experience[1]. This step is then followed by identifying ways of student learning attainment and appropriate mechanisms that will allow conveying concepts of these kinds.

The purpose of this research study is to explore the development of a quality curriculum in high-performance CG (HPCG) education coupled with data describing how students in such courses perceived the content, assessment, and pedagogy they experienced. We utilized Wiggins and McTighe's backward design (1997)[1] as a framework for designing this study. Their backward design process (p.9) is composed of three main stages: (a) identifying the desired *learning outcomes* - the content of the lesson, (b) determining the acceptable *evidence of learning* also called the assessment method, and (c) planning the *experiences and instructional approach* or pedagogy. We used this process as a framework because it encompasses all elements that should be involved in any instructional intervention. Especially, we present the effect of introducing concepts of high performance computing on both edges of the scale. That is, we offer an existing introductory graduate course on one hand, and the development of a new curriculum implemented through an advanced course on the other. We also describe the formative and cumulative mechanisms to collect evidences of student learning and we then concentrate on discussing and presenting a guided inquiry-based learning approach implemented in the introductory and advance courses. Lastly, we complement the description of these elements by identifying student perceptions of the learning outcomes, evidences of the learning and pedagogical approaches.

<u>HPCG Education</u>

CG has recently undergone one of the most advanced developments in all fields of computer science. It is applied in traditional fields, such as scientific visualization, gaming, and computer aided design. Recently, with the development of advanced CG hardware, a new emergent area has appeared where this technology has merged with high-performance computing. With the power of 1TFLOP on a GPU, such as NVIDIA® Tesla, the users have widely applicable software tools and hardware platforms that can be used not only in CG, but also in scientific computing. However, there is no clear way or experience of teaching these mixed approaches. Students and educators alike suffer from these rapidly changing fields. The APIs, such as Cg[2], CUDA[3,4], and OpenCL[5] are changing every six months, and new hardware architectures appear every year.

Guided Inquiry-Based Learning

Various definitions of guided inquiry-based learning exist. Kuhlthau et al.[6], for example, defined guided inquiry-based learning as "inquiry that is guided by an instructional team to enable students to gain depth of understanding and a personal perspective through a wide range of sources of information (p. 2)". On the other hand, Gaddis and Schoffstal[7] defined guided-inquiry learning as "a process that involves experiments [that] combine the pedagogical advantages of open-inquiry methods with the practical advantages of expository experiments. Guided-inquiry experiments, also known as discovery-based experiments, usually provide students with a tested procedure to arrive at a predetermined, but unspecified outcome. (p. 848)". Without loss of generality, in our paper we will follow the definition of guided inquiry-based learning as a mixture of inquiry approaches and direct instruction approaches, where students first learn the concepts and then apply them in scaffolded inquiry-based research activities.

Inquiry-based learning is a pedagogical method that has received great support from educational researchers and educators[8]. It involves students: (a) identifying problems and solutions and the testing of these solutions; (b) designing studies under their own procedures; (c) collecting and analyzing data; (d) discussing the findings and formulations of evidence and/or new questions; (e) linking experience to activities, science concepts, and science principles; and (f) sharing, discussing, and debating procedures, products, and solutions[9]. Opportunities for learning associated with inquiry-based learning are the development of general inquiry abilities, the acquisition of specific investigative skills, and the development of improved understanding of science concepts[9,10]. However, inquiry-based learning has also received extensive criticism[11]. One aspect being criticized is the considerable consumption of classroom time. Another aspect relates to the invalid assumption that students possess the required cognitive skills to engage in inquiry activities. Similarly, from a psychological perspective, Kirschener, Sweller, and Clark[12], provided ample discussion of why approaches such as inquiry-based learning does not work. They argued that presenting students with complete information, perhaps through direct instruction, may result in a more accurate mental representation that can be easily acquired by the learner. Students in our courses solve open-ended problems in advanced CG using the latest CG technologies and developer tools. The guided inquiry-based learning approach is a mixture of inquiry approaches and direct instruction approaches. Students first learn the concepts and then apply them in inquiry-based research activities. The pedagogical method has been implemented during an academic term in two different courses: an introductory graduate course of CG education and an advanced graduate course of HPCG.

Guided Inquiry-Based Learning Approach in HPCG Education

We present a guided inquiry-based learning approach to HPCG education. In our courses, students solve open-ended problems in advanced CG, using the latest CG technologies and developer tools. The guided inquiry-based learning approach is a mixture of inquiry approaches and direct instruction approaches. Students first learn the concepts and then apply them in inquiry-based research activities. The pedagogical method has been implemented during an academic term in two different courses: an introductory graduate course of CG education and an advanced graduate course of HPCG.

These are the research questions for this study:

(a) How do undergraduate and graduate students perceive a guided inquiry-based learning approach implemented throughout the entire academic term?
(b) What are the differences of undergraduate and graduate student perceptions on a guided inquiry-based learning approach?

Methods

Qualitative and quantitative research methods were used to identify student perceptions of the learning outcomes, evidence of the learning and pedagogical method employed in their courses. Our ultimate goal is to identify, compare, and contrast the perceptions of the learning results of beginning and advanced CG students, which will provide evidence of the learning and pedagogical approaches. In this way, we will be able to understand and apply more effective ways of using guided inquiry-based learning approaches with different kinds of learners.

<u>Participants and procedures</u>
Participants of this study consisted of 25 undergraduate and graduate students in Computer Graphics Technology (2 undergraduates, 21 master's candidates, and 2 Ph.D. candidates), who were surveyed at the end of the semester. From the entire population, 19 were from a course entitled *The Development of Graphics in Technology* (CGT511) and 6 were from a course entitled *Advanced Real-Time Computer Graphics Programming* (CGT581C). The introductory course CGT 511 is required of all junior graduate students, whereas the CGT 518C is an optional advanced course for senior graduate students.

<u>Data collection method and data analysis</u>
The data collection instrument consisted of a voluntary Likert-scale survey [13] focused on the students' perceptions of the learning outcomes (five multiple-choice questions and two open-ended questions), evidence of the learning (five multiple-choice questions), and pedagogical approaches (eight multiple-choice questions and three open-ended questions) utilized in their respective courses. Their responses to multiple-choice questions were rated on a scale of one to four: strongly agree (4), agree (3), disagree (2), and strongly disagree (1) to each question. Descriptive statistics were used to analyze and to report the survey's results. Our interpretation of students' responses was considered positive if the responses' average $\mu_s \geq 3.1$, neutral $2.1 \geq \mu_s < 3.1$, and negative if $\mu_s < 2.1$. Moreover, we have compared the mean values for both groups (introductory and advanced) to identify major and minor differences. Students' responses to open-ended questions were analyzed and compared through categorical analysis.

Results

<u>Introductory Course</u>

The first course is the introductory course, which is obligatory for all graduate students. It is a standard 16-week course, and each class is three-hours long. The students have widely different backgrounds ranging from art and design to programming. That is why the main objective of this course is to provide an overview of contemporary CG with a special focus on HPCG. One of its principal objectives is to clearly demonstrate the parallel nature of CG and to focus on computational thinking in terms of parallelization of serial problems.

Learning Outcomes

The course starts with an overview of the human visual system, where students have to compare the classical camera and its mathematical model in CG. Formation of color from light and color perception is another topic that is discussed in depth. Students are asked to explain the concepts in terms of their own perception and they discuss differences between human and animal visual systems.

These topics provide a background for discussion of the problem of computer images and the implementation of sampling and alias. These concepts are discussed from the viewpoint of modern CG hardware. Students then identify and discuss in depth details related to which part can be computed in parallel on the GPU or which must be serialized on the CPU. Students then implement a simplification of an image's color space, using Floyd-Steinberg dithering, or similar approach. The second part of the course deals with a mathematical description of 2-D and 3-D objects with a special focus on adaptive approaches, and techniques for level-of-detail that allow rendering and visualization of massive datasets. Students must implement a project in which they model and visualize a 3-D implicit object. This task is embarrassingly parallel, and special focus is put on parallel implementation. Rendering is the last topic and students discuss it within the context of real-time photorealistic imagining on the GPU.

We report on the students' perceptions of their general experience related to the relevance of the course and its content. Overall, the students were positive in their responses of considering to take this course as a positive experience $(\mu, \sigma) = (3.26, 0.45)$, even though they were neutral in their perceptions of finding its content as highly relevant to their areas of interest $(\mu, \sigma) = (2.89, 0.77)$, and also neutral in their perceptions of finding the homework assignments and projects as highly relevant to their areas of interest $(\mu, \sigma) = (2.57, 0.61)$. They also felt neutral in perceiving the content of this course as a way to be better prepared to do their research or to get a job in industry $(\mu, \sigma) = (2.68, 0.67)$. Students were also neutral on their perceptions of finding the projects and homework assignments as activities that supported their goals and expectations of the course $(\mu, \sigma) = (2.74, 0.65)$. We also asked students to describe their areas of interests as related to homework assignments and projects. Fourteen students responded this question, and their responses were centered on three themes: 1) most students restated that the homework and projects were unrelated to their areas of interest. 2) Some mentioned that some topics discussed in class were related to their areas of interest. 3) A few mentioned some specific examples of how the course was related to their areas of interest, for example: "My study area is 3-D animation based on Maya, which is one of the crucial aspects of CG. For example, the light in Maya includes a Phong model and the like."

Evidence of Learning

The evidence of learning is conducted through assessment mechanisms, such as quizzes, exams, projects, and papers. Quizzes are applied at the beginning of the class to make sure that students have reviewed information from the previous class. Projects are simple enough to be completed with the information provided in the class, and they consist of a $C++$ implementation of basic approaches, such as implicit objects, image dithering, and curve interpolation with a discussion or additional points for the parallel implementation. The most important part of the course is the analysis of scientific papers. Students are assigned very advanced papers, typically from the latest Siggraph or Eurographics conferences. They must analyze the papers, understand them, center them in terms of the knowledge presented in the course, and make a 45 minute presentation that is carefully peer evaluated by students in the classroom. Students are asked to discuss the disadvantages of the presented method, such as weaknesses and possible extensions. The presentation allows showing the theoretical knowledge gained in the class in the context of its practical applications to the contemporary CG scientific problems. An example of a student project is an implementation of Floyd-Steinberg dithering algorithm, or an implementation of a 3-D static field defining an implicit iso-surface.

Here we report students' perceptions of their learning in the course and their perceived transfer of such concepts and skills into practical situations. Focusing on student gained skills, they reported a moderate perception of having learned the latest CG technologies $(\mu, \sigma) = (2.83, 0.62)$ and a positive perception of having learned certain aspects of the latest CG research $(\mu, \sigma) = (3.16, 0.51)$. They were undecided about feeling confident with their abilities to use concepts learned in the course to approach new problems outside the scope of the course $(\mu, \sigma) = (2.74, 0.45)$. Students also reported a perceived moderate performance in their assignments and projects in the class $(\mu, \sigma) = (2.63, 0.76)$ and on their overall performance in the course $(\mu, \sigma) = (2.89, 0.57)$. Moreover, they reported that taking this course supported their learning, enabling them to continue their education in this field $(\mu, \sigma) = (3.11, 0.57)$.

Pedagogical Approach

As discussed above, the most important part of the course is the analysis of scientific papers. The papers are selected in such a way that they match the discussed topic. The instructor presentation covers the basics, whereas the papers typically introduce the most advanced new techniques within the same topic. Each paper is selected to build on the theoretical body of knowledge presented in the classroom in order to complete it with the most advanced topics.

An example is the topic of image manipulation that was completed with a paper[14]. Students in the first class design the classification rubric that is being evaluated. Among things it includes are a structure of the presentation, facts, and clarity of the presentation. The presenters must explain this scientific paper within the context of the knowledge gained in class.

We investigated the students' perceived usefulness of the instructional methods employed in the course. They reported moderate perceptions on finding homework and projects assigned in this course as highly relevant to CG challenges $(\mu, \sigma) = (2.83, 0.62)$. Students also reported moderate responses about their perceptions of their abilities to apply concepts learned in class to solve the homework assignments and projects $(\mu, \sigma) = (2.89, 0.58)$. They had moderate perceptions in identifying the projects as research oriented $(\mu, \sigma) = (2.83, 0.92)$ and also found them very challenging $(\mu, \sigma) = (3.17, 0.62)$. Despite their moderate responses on the instructional approach employed in the course, overall, students reported liking the format of the course $(\mu, \sigma) = (3.00, 0.59)$

When students were asked how the format of the course (e.g., lectures and projects) helped them most during their learning process, they reported the following aspects: (a) it contained interesting and cutting-edge information; (b) it provided a varied amount of information; (c) class demonstrations were very useful; and (d) student presentations were especially useful. Here are some student responses:

> "Lectures were very interesting, entertaining, and well done."
>
> "The in-class demonstrations were very helpful in illustrating relevant concepts."
>
> "The presentations by groups in the class about a very advanced topic that we had just covered was really interesting for me to see."

Students were also asked what aspects of the course format may inhibit their learning processes. Their suggestions were to provide more detailed lecture notes and to solve more homework assignments and projects. Some students, however, perceived aspects of the course to inhibit their learning processes. We also asked them to suggest ways in which the course's format could be more useful and engaging in their learning. The students reported that more projects and more examples would enhance their understanding of the course contents.

> "I would like a more hands on approach whether it be a group project or seeing more examples."
>
> "Maybe a bit more homework to make sure the topics are really understood."

Lastly, students were provided the opportunity to express any comments or suggestions related to the course. The three following responses were submitted:

> "The course is very good overall."
>
> "Awesome class. Learn a lot. Thanks for my professor."
>
> "Despite lack of relevance to my area, one of the most interesting and enjoyable classes I've taken in 8 years at this institution. My professor is an excellent lecturer, very entertaining and able to fit a great deal of information into small amount of time without being confusing or moving faster than students can understand."

<u>Advanced Course</u>

The course is a standard 16-week course with each class being three hours long. Its prerequisites include $C++$ programming and an in-depth knowledge of OpenGL.

Learning Outcomes
The course is divided into small blocks that introduce different approaches to HPCG. Namely, students are introduced to the concepts of Level of Detail, and they must implement a system that efficiently uses the concepts of hysteresis, billboards, and varying objects representation, among other things. Special attention is paid to advanced rendering, such as cube mapping, bump textures, per-fragment shading, and rendering. Another part includes advanced atmospheric phenomena, such as distance-range fog and clouds that need to be implemented using Cg shaders[2]. Procedural texturing is examined by programming an embarrassingly parallel shader that renders nonlinear deterministic fractal on the surface of a 3-D object. Students learn the latest concepts of GPGPU programming, using frame buffer objects by implementing physics-based particle system simulation that is entirely implemented on the GPU. They must efficiently troubleshoot all bottlenecks for comparison to a CPU implementation.

Generally, students were very positive in their responses about considering this course as a positive experience $(\mu, \sigma) = (3.83, 0.41)$. Furthermore, they were absolutely positive in their perceptions of finding the course contents as highly relevant to their areas of interest $(\mu, \sigma) = (4.00, 0)$ and positive in their perceptions of finding the homework assignments and projects as highly relevant to their areas of interest $(\mu, \sigma) = (3.67, 0.52)$. Students reported very positive perceptions in finding the content of this course as a way to be better prepared to do their research or to get a job in industry $(\mu, \sigma) = (\mathrm{M} = 4.00, 0)$. They were also positive about their perceptions of finding the projects and homework assignments as activities that supported their goals and course expectations $(\mu, \sigma) = (3.17, 0.41)$.

We asked students to explain why they were taking the course. Half of them reported they took it because it would help them progress in their research. The other half reported they were interested in learning a specific topic in this course. The students were also asked to describe their areas of interest in relation to homework assignments and projects. All students mentioned some specific examples of topics in the course that were related to their areas of interest.

Evidence of Learning
The evidence of learning is identified through small projects, a semester-long project, and classroom quizzes. The quizzes are applied at the beginning of the class to make sure that students review information from the previous class. The small projects are partially completed in the class, but they are usually too complicated to be finished there, thus they are left as homework assignments. The final project is the most important part of the course. It is delivered in the form of a scientific paper and the goal is to eventually publish the paper. Students need to study the previous work and to write the corresponding part of the paper, they must propose the method, implement it, describe results, and discuss weaknesses and future work. When the class was conducted for the last time in Fall 2010, we were able to submit two of the seven papers. One paper discussed the problem of real-time ecosystem development in urban areas (see Figure 1) and it has been accepted by the high ranking CG conference related to that topic[15]. The other project provided illustrations of 3-D nanoheterostructures (see Figure 2) and the paper is currently under review in NanoLetters[16] one of the highest ranking journals in this field. It is important to note that the time difference between students taking the basic and the advanced course is from two to three years.

Regarding student perceptions of their learned skills, the students reported a positive perception of having learned the latest CG technologies $(\mu, \sigma) = (3.5, 0.55)$ and positive perceptions also of having learned certain aspects of the latest CG research $(\mu, \sigma) = (3.67, 0.52)$. Students reported positive perceptions in confidence with their abilities to use concepts learned in the course on

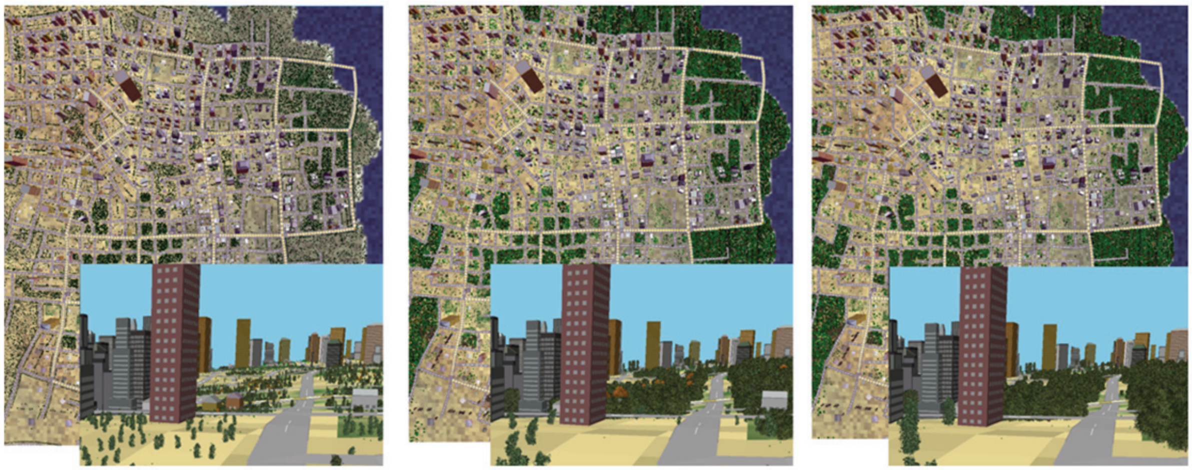

Figure 2. An example of the result of the final project of the advanced course. Plant distribution w.r.t user-defined rules and existing urban layout is simulated on the GPU using CUDA[15].

how to approach new problems outside the scope of the course $(\mu, \sigma) = (3.17, 0.75)$. It is interesting that students reported a moderate perception in their performance on assignments and projects in the class $(\mu, \sigma) = (2.66, 0.82)$, but positive perceptions on their overall performance in the course $(\mu, \sigma) = (3.17, 0.75)$. Students also reported that taking this course supported their learning enabling them to continue their education in this field $(\mu, \sigma) = (3.83, 0.41)$.

Pedagogical Approach
Most of the small projects are of duration of one or two weeks. Through these projects, students directly apply concepts learned in class. For example, in one class we discussed the concept of parallel implementation of procedural texture mapping, using shaders. That day, the small project will consist of implementation of nonlinear fractal on the GPU and its mapping to OpenGL fragments. The course instructor provides students with a simple framework that allows them to go directly to the core of the problem. In our example, this framework will consist of an application that displays a 3-D object and maps uniform color to its surface, using a Cg shader[2].

The course ends with a large project assignment. Examples of projects focus on advanced topics, such as fluid dynamics implementation of Navier-Stokes equations for shallow-water equation on the GPU, using haptic devices to touch the electrostatic field inside a capacitor, using a sketch-based system to reconstruct 3-D trees, and using clustering for level-od-detail, or 3-D volumetric rendering of nanoheterostructures. The role of the course instructor in this process starts with being sure that the topic assigned makes a perfect fit to the area of interest of each student. The instructor then scaffolds the process of inquiry by guiding the student through the previous work, helping with writing the paper, defining the right technique to solve the problem, and discussing the implementation and testing. The instructor also helps by providing software libraries for some advanced procedures.

Students reported positive perceptions on finding homework and projects assigned in this course as very relevant to CG contemporary problems $(\mu, \sigma) = (3.66, 0.51)$. They also reported positive perceptions on their abilities to apply concepts learned in class to solve the homework assignments and projects $(\mu, \sigma) = (3.17, 0.4)$. Moreover, they had positive perceptions in identifying the projects as research oriented $(\mu, \sigma) = (3.33, 0.52)$ and they found them challenging $(\mu, \sigma) = (3.33, 1.03)$. Overall, students reported liking the format of the course $(\mu, \sigma) = (3.00, 0)$.

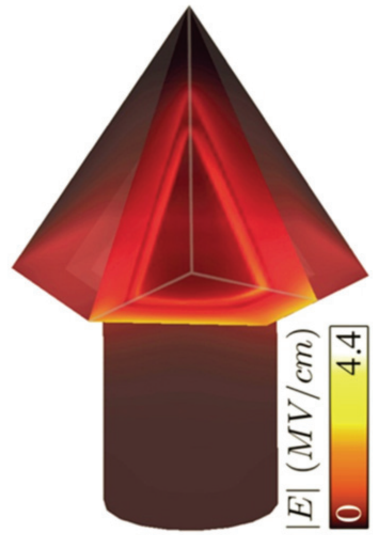

Figure 3. An example of the result of the final project of the advanced course. Three-dimensional electric field magnitude, |E|, distribution within a nanopyramid heterostructure containing a quantum well[16].

When the students were asked how the format of the course (e.g., lectures and projects) helped them most during their learning process, they reported that classroom presentations and projects did. Here are some excerpts from their responses:

> "A research project which passed through the entire course helped improving the research ability."
>
> "The projects were built on what was taught in class and were immediately given after the explanation thus was a good order."
>
> "The project made sure I remember the concepts taught since the concepts need to be applied in the correct manner for the projects to work."

Students were also asked what aspects of the format of the course may inhibit their learning processes. They offered no particular remarks regarding this question. In the question regarding how suggestions by students may help to find ways in which the format of the course could be more useful and engaging in their learning, two students suggested that focusing less on the implementation on code and more on other topics would have been more useful for them:

> "I do feel a little more explanation on certain topics and a few more example code would have been very useful especially during the last few lectures."
>
> "I might have liked a bit more explanation of the more technical concepts instead of looking at how it was done in code."

When students were provided with the opportunity to express any comments or suggestions related to the course, we obtained the following responses:

> “I do feel like I gained a lot of knowledge just from the power point slides and smaller projects. Very few classes in this program give the students the ability to really learn CG topics at a lower [technical] level...”

> “It's an engaging lecture.”

Discussion

Comparing and contrasting student responses from both groups by comparing the mean values, the main difference identified is related to the level of the perceived interests students found on the topics taught in the class and related homework assignments. Those in the introductory course had a moderate perception of finding the contents of this course as a way to prepare them to do their research or to get a job in industry, and those in the advanced course had a very positive perception about this same aspect (Δ=1.32). And though the introductory course students found the content and assignments somewhat related to their areas of interest, the those in the advanced course found them highly relevant to their areas of interest (Δ=1.11). Another major difference identified was related to students’ perceived relevance of the course to current CG challenges. Their beliefs in the introductory course were that the projects assigned to the course were somewhat related to current CG challenges, but their beliefs in the advanced course were very positive in considering the homework assignments and projects of the course as very relevant to CG challenges (Δ=0.83).

Similarities identified by both groups relate to the format of the course and the level of difficulty of the projects. Both groups perceived the homework assignments as very challenging (Δ=0.17) and they had experienced trouble in completing the homework assignments and projects related to the course (Δ=0.04). Despite these challenges, both groups equally reported a positive perception of liking the course format (Δ=0).

Implications for Instruction

The implications of instructing this study can be enlightened through the lens of the ARCS (Attention, Relevance, Confidence, and Satisfaction) motivation model[17] . Keller’s motivation model comprises of four main factors: (a) the attention factor relates to how student attention can be aroused and sustained, (b) the relevance factor relates to how the given material relates to student interests and goals, (c) the confidence factor relates to student perceptions on their ability to be successful accomplishing the given task, and (d) the satisfaction factor relates to positive student expectations of the outcomes of the task. In our study, the attention factor was established by the inquiring nature of the projects and the homework assignments related to the course, where the students had to do research oriented projects and assignments relevant to their own field of research. The confidence factor was established by the level of difficulty of the assignments; that is, although students found the projects and assignments challenging, they had a positive perception of their expected performance on the course. The satisfaction factor was evidenced through student perceptions of the usefulness of the course for their learning and their perceptions of liking the course format. However, one aspect that needs to be refined in the introductory course is related to the relevance factor where homework assignments and projects

need to be more aligned with student interests and goals. This is also related to the fact that the students do not have clear thesis topic at that time.
Another important aspect in teaching in such a widely and rapidly changing area is the role of the instructor. It is essential for the course instructor to be up-to-date with the latest technological discoveries and scientific approaches of CG. The instructor should be able to use them actively and to demonstrate their applicability in a wide area of problems. Making the problems directly related to student needs and problems, for example, related to their thesis, is an advantage that is possible because of the wide application area of CG ranging from scientific visualization, animation, gaming, and real-time simulations to high-performance computing on the GPU.

Conclusions

CG is one of the most rapidly developing areas of computer science. It finds applications in a vast amount of virtually disconnected areas ranging from desk-top-publishing to gaming and scientific visualization. Keeping pace with technological advances, such as the new generations of modern graphics cards that are being released every year, can be a significant challenge. Transforming this development into education is even more challenging.

In our paper, we have attempted to show our experience with teaching HPCG to technology students. We have described this application within the scope of two courses, one introductory, and one advanced course. The strategies of teaching in both are different. The introductory course is more knowledge-transfer oriented, with discussion about the latest papers and problems. The advanced course is problem-solving oriented with a strong stress to implementing a solution using the latest CG technology.

As for the results, we believe we have shown that this approach has a positive effect in various ways. First, the engagement and positive attitude of students is evident in both the basic and the advanced course, but it increases significantly with time. Second, we have shown evidence that most students are able to *understand and conceptualize* very advanced contemporary topics after visiting one semester of the intensive introductory course. This has transformed into *active knowledge* in the advanced course, where students are able to solve a wide variety of scientific problems with an immediate publication capacity at highly-rated conferences and journals.
As evidenced from the results of this study, a guided inquiry-based learning approach may be an effective pedagogical method to be used in HPCG education because it has been perceived by students to be useful for their learning.

As possible avenues for the future work we would like to compare guided inquiry-based learning approach with the traditional methods that involve teaching only. Another interesting topic would be to abstract from the area of CG and study pure HPCG methods using GPUs. Another possible future work would measure the effectiveness of the guided inquiry-based learning approach as a function of the student performance. Only two undergraduate students were included in the assessment of the advanced course and it would be valuable to increase this number by running the test over more semesters. Last but not least, the introductory course is a required course that could have affected the results.

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