DO YOU WANT A STRONG CLASS? “CULTURE” IT!

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Abstract

We are given a class of 15 graduate students and we are asked to teach them Graph Theory focusing on its practical aspects, i.e., highlighting how graph theory has and can be used to address real world problems. Students are of various undergraduate profiles including computer science and engineering, mathematics, civil engineering, business administration and of various backgrounds regarding graph theory. The objective is to motivate them appropriately so that at the end of the semester they all appear a homogeneous, high-level background on this particular area of graph theory. What could be an efficient approach towards this objective?

A possible direction could include intense teaching and lectures on advanced topics coupled with assignment and study of relevant published work. Using this approach, a successful outcome would be heavily based on personal effort put from individuals: a teacher, who would have to prepare and present detailed, rigorous lectures and students, who would have to work hard on an individual basis on relevant research work. However, given the various scientific background of students, such an approach would suffer an important drawback. A teacher would have to assume a minimum class background level as a starting base for further discussion on advanced topics. Using a very low "minimum" is inefficient in terms of time; using a very high "minimum" is ineffective in terms of maintaining class homogeneity. No matter how this initial decision is made, what usually happens next is that some of the students through hard individual work manage to catch up contributing to achieving the course goals while the rest of the students get lost in the way and either fail or hardly pass.

What if an alternative approach were used according to which a class is not seen as a set of individuals but, instead, as a society where the overall objective is finally obtained via the development of a “course culture”. A culture is not just a collection; there is a mode of relationship operating between the individuals of the culture, namely, communication. The culture of the group consists of the totality of the individual world views united by bonds of communication.

We implemented this approach for a semester period in the context of our graduate course in a computer science and engineering graduate program. In particular, all course activities were conducted in a cooperative way. Lecturing was replaced with extensive discussion on new terms and concepts. Problem-solving sections were replaced with thorough study and brainstorming within groups before proceeding to suggestion and analysis of solutions to particular questions. Assignments were conducted only in groups.

Our findings are indeed impressive and encouraging. Having started with a rather heterogeneous class of very weak background in elementary graph theory, we ended up with a pretty strong, homogeneous class showing clear evidence of a common graph-theoretic culture. Knowledge and experience was communicated within the class creating a cultural environment shared by all participants. This induced cultural environment not only did it promote understanding, skills and potential of individual participants but also further enabled creativity and highly elevated the research potential of the whole class.

Keywords: Culture, teaching, computer science, higher education, graduate program.

1 INTRODUCTION

Graduate classes are often composed of students of various undergraduate profiles and various backgrounds regarding the technical aspects of each course. In this context, a critical and challenging issue that usually teachers have to address is the teaching approach they should follow in order to motivate students appropriately so that at the end of the semester they all appear a homogeneous, high-level background on the particular scientific/technical area of their course.

A possible direction could include intense teaching and lectures on advanced topics coupled with assignment and study of relevant published work. Using this approach, a successful outcome would be heavily based on personal effort put from individuals: a teacher, who would have to prepare and
present detailed, rigorous lectures and students, who would have to work hard on an individual basis on relevant research work.

However, given the various scientific background of students, such an approach would suffer an important drawback. A teacher would have to assume a minimum class background level as a starting base for further discussion on advanced topics. Using a very low "minimum" is inefficient in terms of time; using a very high "minimum" is ineffective in terms of maintaining class homogeneity. No matter how this initial decision is made, what usually happens next is that some of the students through hard individual work manage to catch up contributing to achieving the course goals while the rest of the students get lost in the way and either fail or hardly pass.

So, what could be an efficient approach?

In the following, we describe our experience with a graduate course entitled “Graph Theory and its Applications to Real-World Problems” offered in the context of the graduate program “Computer Science and Technology” at the Department of Computer Engineering and Informatics, University of Patras (Greece). The graduate class consisted of 15 graduate students of various undergraduate profiles, including computer science and engineering, mathematics, civil engineering, business administration, and various backgrounds regarding graph theory. According to the teaching approach we used, the class was not seen as a set of individuals but, instead, as a society where the overall objective was finally obtained via the development of a “course culture” based on intense communication among the society members and on the establishment of a shared conceptual and social space favouring evolution. On the basis of obtained results and observations, our approach could suggest a very good practice for effective class functioning, at least at a graduate level.

In the following sections, we present in detail our methodology (Section 2) and provide implementation details as well as our findings and observations (Section 3), which are impressive and encouraging.

2 METHODOLOGY

In this section, we first describe our view on culture on which we built our teaching approach. Then, we present the course context, the class synthesis and background and the teaching approach we implemented together with our findings.

2.1 Our view on a course culture

Our view on the concept of a “course culture” largely coincides with that stated and analyzed by Wilder in his influential book on “Mathematics as a Cultural System” [5]. A culture of an average person in a modern society consists of the general collection of beliefs, prejudices, ways of interacting with others and the knowledge required to complete a job, whatever that may be. Unlike the acquisition of new knowledge, this collection was neither invented nor discovered by a particular person. In fact, the most of this collection existed before the existence of that person who eventually acquired it through contacts with others via a communication process.

In this context, culture can be defined as a collection of cultural elements like customs, beliefs, tools, mores, etc, possessed by a group of people who are related by an associative factor (or factors) such as common language, membership in a group (social, professional, …) or geographical contiguity. Despite the fact that all group members seem to "think alike", no individual person in a group will possess all the culture of that group and no two individuals share exactly the same world view since individual differences due to heredity and surrounding contextual environment preclude it. Therefore, the culture of a group consists in the totality of the individual world views interlaced by bonds of communication.

As Wilder aptly point out, gears in an engine form a nice analogy capturing how culture and its individuals interact. Each gear in an engine is related to the totality of other parts of the machine in a definite fashion and contributes to the functionality of the engine. This relationship is reflected by the overall engine plan and operates through the contacts of the gear with other machine components. In the case of a culture, communication is a similar mechanism which operates between the individuals of the culture. The common language forms the basis of communication in a culture connecting the parts of culture possessed by an individual to those possessed by others.

What can be the relationship between an individual and the individual's culture? This question has received various answers from anthropologists, which, however, point to two opposite directions. One direction claims that individuals actually create the general culture where they participate since new
concepts, inventions, etc are usually devised and contributed to the culture by individuals. According to the other direction, culture attributes particular characteristics and properties to its individual members, focusing on the way a cultural environment determines individual world views through values, beliefs, etc.

We adopted a similar view for culture wishing to apply it in the context of our graduate course. Individual members – students and teachers – play the role of engine gears and have their own world views which must be brought together and be fruitfully intertwined within a single society, namely a class. This society must function as a fine-tuned engine fulfilling the course objectives and letting students improve and evolve. To do so, a sort of culture must be developed in the sense that the class, exploiting communication, must eventually share a collection of common beliefs and mores, ways of interacting with others and the knowledge required to successfully complete the course. A bidirectional relationship must be established between individuals and this desired course culture. More precisely, on the one hand, new concepts, innovative approaches and solutions, etc must be devised and contributed to the culture by individuals; on the other hand, the desired course culture must attribute particular characteristics and properties to its individual members through values, beliefs, knowledge, skills.

The recent book entitled “Wait, What? and Life’s Other Essential Questions” [4] authored by James Ryan, dean of the Harvard Graduate School of Education¹, played a crucial role and inspired the implementation details for the development of the desired course culture. More precisely, according to Ryan, “there are five essential inquiries, “Wait, what?”, “I wonder . . . ?”, “Couldn’t we at least . . . ?”, “How can I help?” and “What truly matters?” that generate understanding, spark curiosity, initiate progress, fortify relationships, and draw our attention to the important things in life”.

Throughout the duration of the course, towards the development of the desired course culture, the class was strongly encouraged to frequently ask these important five questions. As Ryan points out: the first question, “Wait, what?”, lies at the root of understanding and suggests that we should all make sure that we understand what we are told, regardless of variations of the surrounding context. The second question, “I wonder . . . ?”, coupled with “if” or “why” constantly reminds us to remain curious. The third question, “Couldn’t we at least . . . ?”, forms an extremely important motivation for progress. The fourth question, “How I can help?”, implies that not only is it important to help, but it really matters how we help, and so asking how we can help will probably make our help more effective. The fifth question, “What truly matters?”, is worth asking on a daily basis not only in the context of a course but especially with respect to big decisions in life.

2.2 Course context

In the context of the course, we study graph theory with a special focus on its applications to real-world problems. Graph theory forms a branch of mathematics and makes a tool for formulating problems, making them precise and defining fundamental interrelationships. Graphs have wide-ranging applicability to practical problems which are usually extremely complex and wide-ranging, including problems on communication, transportation and urban services, energy, the economy, ecosystems, genetic changes, social problems, etc.

The use of precise, graph-theoretical reasoning can cast light on such problems, provide tools to help in making decisions about them, and help in finding answers to a variety of specific questions which arise in the attempt to tackle the broader issues. Graph theory is a tool which sometimes solves problems and sometimes provides insights. Formulating a problem precisely helps us to better understand it. Sometimes a part of a large problem corresponds exactly to a graph-theoretic problem and that problem can be completely solved. On the other hand, the precise formulation of a problem in graph-theoretical language is enough to give us insight on why the problem is hard. Even when enough simplifying assumptions are made to state a problem graph-theoretically, that problem has not been solved and is at the frontiers of current mathematical research. Graph theory is usually used along with many other tools, mathematical and otherwise, for understanding in small ways the large problems which our society faces and some of their possible solutions [2].

Furthermore, in the context of the course, special emphasis is placed on the relation between graph theory and the understanding of the complex way modern society is connected, addressing fundamental questions about how the social, economic and technological worlds are connected. The

¹ http://www.gse.harvard.edu/about/dean
explosive growth of the Internet and the Web, the emergence of social networks and recent technological advances enabled an enormous user population to become actuators in a new emerging connected environment. Easy global communication and rapid and intense spread of information around the world “involve networks, incentives, and the aggregate behavior of groups of people; they are based on the links that connect us and the ways in which each of our decisions can have subtle consequences for the outcomes of everyone else” [1].

In this setting, lectures are organized in a three-level hierarchy. The first level is essentially an introduction to graph theory which includes basic terminology and concepts, important graph classes and their structural properties and corresponding metrics as well as a detailed discussion on the use of graphs as models for various real-world problems. Then, fundamental problems, including graph traversal and covering, detection of Eulerian and Hamiltonian cycles and paths, graph coloring, matching, together with corresponding real-world instances are discussed. Finally, a shift is made towards modern social networks. In particular, we study structural issues, factors contributing to network formation, global and local factors affecting structural balance (i.e., friendship and antagonism), revealing macroscopic properties of the network.

2.3 Class synthesis and background

Graph theory, as a part of theoretical computer science, usually attracts a rather small portion of the student population mainly due to the hardness of establishing a direct and appealing connection between abstract models and state-of-the-art technologies and applications. It is often the case that the audience of courses on graph theory is polarized between students who have a strong relevant background and interest and students who lack the necessary background and conceptual familiarity, and, thus find it extremely difficult to efficiently and effectively follow such courses.

In our case, based solely on the course description, 15 students - corresponding to a 25% of the graduate class of the year - selected this particular (elective) course. Among them, 7 had a degree in Computer Science and Engineering, 1 had a degree in Civil Engineering, 2 had a degree in Mathematics, 1 had a degree in Business Administration and 4 had a degree in Computer, Communication and Networking Technology. In this particular class, only the 7 students with a degree in Computer Science and Engineering had previously taken a course on graph theory as undergraduates. However, even before this information being available, a short introductory test was conducted for determining the class background on elementary graph theory and relevant applications. The test included the following 22 short questions (Table 1).

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
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<tbody>
<tr>
<td>1. What is a graph?</td>
<td>12. What is an Eulerian circuit in a graph?</td>
</tr>
<tr>
<td>2. What is a directed graph?</td>
<td>13. What is a Hamiltonian circuit in a graph?</td>
</tr>
<tr>
<td>3. What is the degree of a vertex?</td>
<td>14. Problem statement: Given a weighted, undirected graph, find a circuit of minimum total weight which visits every graph vertex exactly once and returns to the starting vertex. Name this problem.</td>
</tr>
<tr>
<td>4. When a graph is complete?</td>
<td>15. Is the previous problem solvable? If yes, briefly describe how.</td>
</tr>
<tr>
<td>5. Draw the $K_3$ graph.</td>
<td>16. Which problems belong to the class NP?</td>
</tr>
<tr>
<td>6. Draw a 3-dimensional hypercube.</td>
<td>17. When a graph is planar?</td>
</tr>
<tr>
<td>8. Draw the $K_{3,3}$ graph.</td>
<td>19. When a graph is a tree?</td>
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<td>9. When a graph is connected?</td>
<td>20. What is a complete binary tree?</td>
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<td>10. When a graph is strongly connected?</td>
<td>21. How many leaves a complete binary tree of height 8 has?</td>
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<tr>
<td>11. What is a weighted graph?</td>
<td>22. Give the BFS and DFS ordering of the vertices of the given graph.</td>
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Note that there was no previous preparation required for taking the test. The reason was that our objective was to determine the conceptual familiarity of the students with the graph-theoretical
language, i.e., their “culture”, not to evaluate their performance on assigned tasks. Results are depicted as an ordered sequence in Fig. 1 (lower line) and by individual in Fig. 2 (right column). As it can be observed, at most 8 out of the 22 questions were answered correctly. Best scores were obtained by students with a degree in Computer Science and Engineering while lowest scores were obtained by students with a degree in Civil Engineering and Mathematics.

Overall, this initial feedback made it clear that the class presented a divergent, rather weak background in graph theory. However, taking into account replies to particular questions indicated that this particular class showed a potential for evolution.

2.4 Teaching approach

Given the synthesis and background of our graduate class, what would be the best teaching approach to follow?

One option could be to set as a primary objective to cover the course material as planned, building on hard work required from students and intense teaching (lecture and assignments) required from the teacher. Then, a successful outcome would be heavily based on personal effort put from individuals: a teacher, who would have to prepare and present detailed, rigorous lectures and students, who would have to work hard on an individual basis. But students are sort of discouraged, tending to avoid study when requirements are too high and, then, teachers tend to gradually limit their motivation and effort.

An alternative option would involve redetermining, i.e., limiting, course objectives and focusing on providing students with a strong motivation to catch up. However, given the various scientific backgrounds of students, such an approach would suffer an important drawback. A teacher would have to assume a minimum class level as a starting base for further discussion on advanced topics. Using a very low "minimum" is inefficient in terms of time; using a very high "minimum" is ineffective in terms of maintaining class homogeneity. No matter how this initial decision is made, what usually happens next is that part of the students through hard individual work manage to catch up contributing to achieving the course goals while the rest of the students get lost in the way and either fail or hardly pass, still lacking the desired knowledge and background.

Motivated by our vision for the development of a “course culture” encompassing principles described in detail in section 2.1.1, we decided to go for a dual target: (i) pursue course objectives and covering the course material as planned and (ii) provide all students with a strong motivation and interest to reach a “maximum” in terms of both individual and group/class performance. We focused on establishing a “course culture”, i.e., a common reference framework and activation environment involving intense communication among all individuals of the class. In the next section, we provide implementation details and observed results.

3 COURSE CULTURE IMPLEMENTATION AND RESULTS

Towards our objective for developing a course culture, we decided that all course activities should be conducted in a cooperative way. Students formed 3-5-member groups, which were the basic clusters of the class. Lecturing was replaced with extensive discussion on new terms and concepts. Problem-solving sections were replaced with thorough study and brainstorming within groups before suggesting and analyzing a solution to a particular question. Assignments were conducted only in groups.

In the following, we describe implementation details intertwined with obtained results.

**Lecturing was replaced with extensive discussion on new terms and concepts.** The main intuition was to guide students to discover knowledge, motivating and encouraging them to ask questions and look for answers instead of just presenting terms and concepts to them. For instance, instead of giving students the definition of a graph, we started with simple real-world, practical instances which are modelled using graphs. Then, students were asked to search, study and come up with a formal definition. Furthermore, instead of providing statements of the graph coloring problem together with hardness results and relevant algorithmic approaches, we referred to the use of the graph coloring problem for modelling various real-world communication and scheduling problems, map coloring, as well as applications of this particular problem for the detection of structural properties (i.e., bipartite graphs) or low-cost connected structures (Minimum Spanning Trees). In this way, students were motivated to look deeper into the graph-theoretical problems and discover definitions, hardness properties and solutions. We stress again that all such tasks were completed in a groupwise manner and findings were discussed and further clarified and investigated through discussion and
collaborative work in class. An important advantage and benefit of this method was that all groups - and also individual students - were essentially required to have gained a deep understanding of issues under discussion in order to be able to participate equally in the activities of the class "society". Good students via their willingness and skills pulled weaker ones, motivating and helping them to go one step further. Students with a weaker background had a strong motivation to study in order to be "socially" active members instead of just passive receivers and, thus, contribute to the course society. After all, a successful course session and a fruitful discussion was actually a prize students won; the teacher, though, maintained a guiding role, showing students the way, but letting them explore and discover the scene.

Assignments were conducted only in groups and problem-solving sections were replaced with extensive study and brainstorming before suggesting and analyzing a solution to a particular question. Every discussion session was followed by the assignment of exercises and problems on relevant issues. Groups were given a week to work on assignments and present solutions. Groups submitted their reports and presented obtained results in class. Collaboration and detailed discussion was strongly encouraged. It is worth-mentioning that the outcomes of this procedure included (i) innovative and elegant solutions suggested for hard questions and (ii) extremely creative approaches produced without teacher's guidance or interference. We indicatively mention that solutions of particular research interest were suggested for open issues posed by Easley and Kleinberg in their book “Networks, Crowds, and Markets: Reasoning About a Highly Connected World” [1]. In addition, efficient simulations were developed for the visualization of concepts and methods presented by Rosen in “Discrete Mathematics and Its Applications” [2]. Furthermore, in their effort for an excellent presence in class, groups produced fresh educational material of high quality which can be further exploited by future classes. Important benefits obtained by this approach include the cultivation of collaborative behavior promoting solidarity instead of antagonism as well as increased willingness to work hard for experiencing a decent and respected “social” presence, diminishing the need for cheating while creating room for improvement and evolution.

There was no explicit examination procedure. We decided not to implement an explicit, concrete evaluation procedure in the form any sort of exam (intermediate or final). The main reason underlying this decision was the promotion of self-improvement and solidarity instead of antagonism. Of course, differences in analytical ability, conceptual understanding, scientific progress, willingness to work hard and overall performance were clearly observed and properly recognized within the class society. However, the existence of such differences functioned in an absolutely unifying and motivating way for the class as a whole, promoting acquisition of knowledge, collaboration and solidarity, respect, effort for improvement. In addition to weekly assignments, the 3 groups were requested to thoroughly study three particular thematic sections and prepare to lead and support the corresponding discussion in class. Obviously, this procedure was characterized by an extremely high risk. Students were unfamiliar with complex concepts and ideas addressed in these thematic sections. Both hard work and strong collaboration were required for a successful outcome. Acting as individuals motivated by pure selfish incentives might have led to an extremely poor overall result. However, it seems that the course culture developed in the meantime diminished the failure probability. The class showed an impressive degree of responsibility, worked hard and presented work of very high level during the corresponding discussion sessions. We also observed that "social" influence can have a stronger impact than antagonism. More precisely, we observed that the "indirect comparison" coupled with "social influence" both of which inevitably happen within the class society can motivate students more efficiently than direct comparison (e.g., through partial grading). Furthermore, assignments on regular basis can support learning significantly better that any sort of short exam. Gradual discovery of knowledge improves students' analytical ability and, therefore, raises interest and motivates new, more complex questions.

However, at the end of the semester, two activities of self-evaluation took place.

First, a voting procedure was implemented. In particular, students were asked to anonymously cast their vote for all members of the class society ranking them in 3 categories (namely, 1, 2 and 3, in increasing evaluation order) in terms of their overall standing (technical performance and class behavior). Results are depicted in Fig. 3 and are indeed impressive. The class eventually developed a common culture through which strongest and weakest members were recognized almost unanimously. However, strong bonds of communication, induced solidarity and tolerance, as it can be observed by the important difference in the final scores (actual and obtained via voting) for the weakest members, represented by the orange columns in Fig. 3.
The second self-evaluation activity was the repetition of the test initially given to class members. Students were asked to answer again – also without any particular preparation – the questions given to them during the first meeting. Results are depicted as an ordered sequence in Fig. 1 (upper line) and by individual in Fig. 2 (left column) and are, again, quite impressive. A class with a poor initial average picture (an average of 15% of correct answers) eventually evolved to a fine-tuned “engine” where members (on average) could easily deal with approximately 80% of the posed questions. However, even more important is the fact that these results were achieved without previous preparation; this clearly highlights the degree of acquired knowledge and progress. The degree of individual progress is also impressive. We indicatively focus on two class members (no 5 and 11 in Fig. 2), who started with almost zero familiarity with the course terms and concepts and finally achieved very significant improvement.

The role of the teacher. In this “course culture” development procedure, the teacher performed a rather transparent but crucial role. More precisely, the teacher must focus on the efficient organization of the course before its starts and on the intense and efficient communication with students during the semester.

In particular, the teacher is required to work hard before the beginning of the course in order to organize an appropriate “course culture” strategy. For developing such a strategy, a teacher should build on the three following pillars:

(a) Careful selection of issues to be discussed and relevant supporting material. When the complexity of terms, concepts and methods increases, a usual question a teacher has to address is “What do I need these for?” Such a question comes quicker in the context of courses relevant to the theoretical vs the applied side of a science (computer science, in our case). Students can more easily conceive and appreciate good software or a good algorithm/technique when they write a program for it, since corresponding results are straight-forward. However, when it comes to the analysis of a method/algorithms or the production of a typical proof in the context of a graph-theoretical problem, one can see neither a piece of code running nor results on a display! Our experience has shown that, in such cases, starting with simple observations in very practical scenarios and then proceeding gradually to the corresponding theoretical framework constitutes a very motivational approach that “makes sense”. Of course, this approach cannot be followed for all theoretical courses: no oversimplifications must be made for the shake of conceptual simplicity; however, in our case, the context of the particular course was absolutely appropriate for this approach.

(b) Appropriate ordering of the discussion sections. Issues of foundational nature should be the first to discuss. Advanced issues and student “lectures” should follow. In addition, the vast majority of terms and concepts included in subjects for student lectures should have been discussed before the preparation of these lectures. A critical dilemma during the course preparation phase was regarding the extent to which basic, elementary issues should be covered. It finally seemed that appropriate assignments and strong collaboration significantly helped in limiting time spent on this initial, though absolutely necessary, phase.

(c) Creation of balanced assignments. Assignments should be designed in such a way so that students with a strong background would have the chance to further improve it and exploit their talent and potential while, at the same time, students with a weak background would be motivated to gain knowledge and improve their skills, thus, increase their interest in the scientific area and activities of the course. All weekly assignments included questions and problems ranging from simple, but not trivial, to particularly advanced. Our overall (rather high) expectation was to receive correct answers for at least 60% of the questions from at least 80% of the class. In practice, this expectation was eventually met with very interesting results produced for particularly advanced problems.

In addition, during the semester, the teacher must maintain very frequent and efficient communication with students, placing special emphasis on venues like the Internet and the Web and applications which are very popular among all modern people (especially younger ones), like social networking (e.g., Facebook), messengers, email, the course website/blog. Our experience has shown that a teacher continuously and immediately (as much as possible) available on Facebook or a messenger to help his/her students with answering questions or clarifying grey zones can actually have a catalytic impact and contribution to their progress. First, because students experience feelings of solidarity, equity and inspiration, in the sense that “the person asking them to study and devote time on a course, also studies himself/herself and also devotes time on this course”! The teacher must be the team’s inspirational “captain”. Second, because a teacher clarifying an issue/question/difficulty as soon as
possible encourages students to proceed instead of swinging around grey areas, which works in reverse and eventually has a negative impact on progress.

Figure 1. Overall change in the evaluation scores at the beginning (“Before”) and at the end (“After”) of the semester.

Figure 2. Change in the individual evaluation scores at the beginning (“Before”) and at the end (“After”) of the semester.
4 CONCLUSION AND FUTURE PLANS

In this work, we described our experience with a graduate course entitled “Graph Theory and its Applications to Real-World Problems” offered in the context of the graduate program “Computer Science and Technology” at the Department of Computer Engineering and Informatics, University of Patras (Greece). The graduate class consisted of 15 graduate students of various undergraduate profiles, including computer science and engineering, mathematics, civil engineering, business administration, and various, rather weak, backgrounds regarding graph theory. In our attempt to achieve our dual target: (i) pursue course objectives and covering the course material as planned and (ii) provide all students with a strong motivation and interest to reach a “maximum” in terms of both individual and group/class performance, we developed a “course culture”, i.e., a common reference framework and activation environment involving intense communication among all individuals of the class. All course activities were conducted in a cooperative way. Lecturing was replaced with extensive discussion on new terms and concepts. Problem-solving sections were replaced with detailed brainstorming before suggesting and analyzing a solution to a particular question. Assignments were conducted only in groups. This induced cultural environment not only did it promote understanding, skills and potential of individual participants but also promoted progress, respect, tolerance and solidarity, enabled creativity and highly elevated the research potential of the whole class. As an overall result, having started with a rather heterogeneous class of very weak background in elementary graph theory, we ended up with an improved, pretty strong, largely homogeneous class where communicated knowledge and experience created a vivid course culture with evident capacity for evolution.

We continue to work and refine our course culture development strategy in the context of other graduate courses. Obtained results so far are very encouraging. It is within our future plans to investigate whether and how this idea can be extended to more populated classes like for example in classes for undergraduate courses. Obviously, this is a very ambitious and extremely hard goal mainly due to difficulties induced by the very large number of students attending undergraduate courses, the vast diversity in their scientific and technical background, strict administrative procedures (like grading, graduating, and so on) and a rather vague and loose regulatory framework. However, the inherent way in which human societies create and develop culture with potential for evolution is certainly inspiring and can be enlightening for the development of improved educational approaches.
ACKNOWLEDGEMENTS

Special thanks to Panagiotis Barlos, Merkouria Dimopoulou, Angela Kalapodi, Thodoris Kouvelas, Thodoris Livanos, Andreas Mallas, Marios Michalis, Dimitris Papagiannopoulos, Efi Prappa, Anta Prappa, Christina Savou, Christina Spyropoulou, Giannis Tsaktsiras, Kostas Vlachos, Nasia Zacharia, who were the 15 graduate students in this particular class of Fall 2016, for their invaluable help, active participation and support.

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