

## TEACHING STRATEGIES FOR UNDERGRADUATE HEAT TRANSFER COURSES

Washington Braga  
ME Department, Pontifical Catholic University of Rio de Janeiro- PUC-Rio,  
Brazil

***Abstract:** Enhancing engineering education has been related to the improvement of students interaction. However, time constraints and an always increasing syllabus are on opposite sides, making things difficult for faculty members willing to implement constructivism concepts. These concepts may require more time and less material to allow building up knowledge during a term. The solution may be the Internet, provided that strong interaction is obtained among students, teachers and whatever software used. A mixed environment combining virtual and on-site classes has been developed and used for sometime now. Students acceptance is generally quite good and often their academic achievements have increased significantly, mainly after an email conference system and more interactive web pages have become available. This paper presents some of the strategies and resources combining active and reflective techniques already implemented to enhance students learning.*

### 1. Introduction

To my knowledge, one of the most important advances regarding modern engineering education has been the development of what is generically called web based education, either as a fundamental tool for distance learning or as an enhancing one for face-to-face classes (on-site). However, to me, the real achievement is not the countless plethora of fascinating technological resources. Instead, it is the fact that the Internet is a powerful engine pushing so many clever and interesting discussions on what learning and teaching are for the present day students. More than the resource itself, I feel that truly important is its very existence, as a non-neutral technology, changing everything, beginning with the students minds, just by being there. Therefore, it is not much to say that the development and implementation of an academic environment suitable to a new audience is one of the top priorities among those interested in promoting changes in Engineering Education.

This paper presents some reflections on teaching strategies to promote active teaching that may result in effective learning. Most of them have been used for some time now in an undergraduate Heat Transfer course at the Mechanical Engineering Department of PUC, Catholic University of Rio de Janeiro, Brazil. This is essentially an analysis course, that is supposed to give fundamental information on Heat Transfer. A following course called Thermal Systems Projects is oriented towards technical and industrial problems. The learning environment to be considered herein is an extended classroom, combining synchronous (face-to-face meetings) and asynchronous (using Internet email conferencing systems) learning discussions, centered on active students participation in a collaborative environment. Under no circumstances, a "best" strategy will be presented as experience indicates that the most effective one depends strongly upon the profile of the students undertaking the course, the instructor's profile and teaching philosophy and the course subject. Therefore, the goal of this essay is to present several successful techniques, hoping that some of them may be useful to others facing similar needs. Despite all the technical

resources used or available for the students, my teaching is based on the belief that my role as an instructor is still much more relevant than being a mere presence in the classroom, especially for undergraduate students, as some advocate. Technology is used only for improving the educational process.

In the past, technology changes were less drastic and there was more time allowed for individuals to learn and master the newest technology. The Internet literature is full of similar examples, from the invention of press to television. These days the new requirements and the economic restrictions have a more dynamic nature. Savater<sup>1</sup>, a Spanish philosopher, has mentioned that almost everything in human society has a pedagogical intention and the need to share what we know with those who do not know it is part of our nature. So, teaching and learning are what we do the most, perhaps not always efficiently. However, there is now a different student and a different economic scenario; it is not important who or what comes first. As a consequence, a new teacher capable of adjusting the learning process accordingly is becoming more and more necessary. It has been stressed in literature that nowadays students need to know more about collaborative work, self learning, must have good reading and writing skills, computer literacy and so on. Therefore, teachers have to grasp a deeper understanding on such pedagogic topics and also on how people learn. Consequently training teachers is exactly what we should do. The first question we pose is how to do it rather than what to do. To my experience, without the Internet, there would not be any hope to do all that it is necessary, either on the teaching or on the learning part.

The strategies were developed to be used in an environment that deals with on-site and online classrooms. They are discussed having in mind the limitations students have to access Internet from their homes in Brazil, where fast communication lines are still quite expensive. So, no discussion about real time conferences or animations will be presented, although I have already had some experience in this subject. Firstly, the online strategies will be introduced and then, the ones for on-site classes., hoping to make it clear that this division is used only for presentation purposes since they interact all the time. A more detailed discussion on teacher and student training to increase the benefits for an effective learning will be submitted to publication elsewhere,( Braga<sup>2</sup>) due to space limitations.

## 2. Internet (Asynchronous) Classroom

After a couple of years developing and implementing different resources, the collection of available tools is already quite large. Among others, students now have access to web pages containing texts, slides, spreadsheets, Fortran programs, extensive frequently asked question files, conference systems, self correcting quizzes, Java applets, tutorials with automatic answers analysis and similar resources. As learning is a personal experience, not everybody does learn the same way. Therefore, it was found necessary to offer a large number of academic resources that are supposed to motivate different students. On their first day of class, students receive a written summary about them, besides the course syllabus, with plenty of information on how to handle such resources, how to select passing criteria (students may choose weights for four types of academic evaluation tools: three monthly tests, a final examination, projects and online plus classroom participation), hints on oral presentations, netiquette and others. The summary is also available online.

To give some flavor on how such material is being used, two of them were selected to be presented herewith. The first one is the email conferencing system and the second one is the Java applets, coupled to the tutorial. To my understanding, the first one is the most important single element for virtual active learning, much more important than the mandatory web pages, and for this reason only, it will be discussed first.

## 2.1 Email Conferencing System

With the creation of the Bulletin Board Systems, BBS, one of many private communication mediated by microcomputers was introduced, allowing fast exchange of ideas and discussions. Present day learning networks use intensively computer conferencing systems which have huge academic potentials as known to everyone already involved in such systems, e.g. Harasin<sup>3</sup>.

After using a newsgroup conference and a discussion list, both developed for an UNIX environment, I came to know the benefits of using an email conference service, (e.g. the one available at <http://groups.yahoo.com>), simple to use (a must requirement) and easy to manage. Being a ME professor with limited time and financial resources to spend on information technology issues as these, the no-frills service offered by Yahoo suits me just fine. Enrolling students in the conference, dropping them, up and downloading files to the conference and the managing of a few other resources, are quite simple. It was found important to let students decide by themselves if they should participate or not. A brief invitation note is sent and they have to decide afterwards whether they will join it or not. Most of the students choose to do so. As a result of being such an easy resource to use, student's participation was quite high: last year, there were more than one thousand emails in each term (4 months). The last term distribution appears below:

• Number of emails:	1084	
• Number of valid emails:	777	
• Number of students:	25	
• Emails from the system:	40	5,1% of the valid ones;
• Emails from the instructor:	88	11,3% of the valid ones;
• Emails from the students:	649	83,5% of the valid ones;
• Emails from best contributor:	73	9,4% of the valid ones;

As it is indicated, not all contributions are relevant for Heat Transfer learning and some 30% of them were dropped. However, the remaining number is still quite large and even considering the fact that the instructor (that is, me!), besides being perhaps a bit useful understands that the knowledge construction of efficient students requires that they find the answers to the questions presented by their peers on their own. Periodic instructor intervention was found to be necessary for at least three reasons:

- Students should always be guided since their discussions tend to drift away due to their limited experience;
- Students are able to answer most of their own questions, often in pieces. Many times, however, they do not understand that they are actually learning something, that is, that their knowledge is being built. This is noticed whenever some students, in an attempt to answer the same question, ended up posing different aspects of the same answer and often, none of them is able to sum up the contributions to obtain the "correct" solution. So, a final summary to be made by the instructor is eventually needed;
- For some reason yet to be understood, a few apparently simple questions are just ignored by the group. Recognizing that students need and really appreciate feedback, now and then the instructor must jump into the discussion to give answers to those forgotten questions;

The importance of such off-class discussions became evident when it was noticed that a large number of them relate deeply to the subjects being discussed in the classroom. Students do need extra time to think about them, indicating that reflective learning is also an important aspect of the process. Off-hours online meetings allow such extra time. Experience has indicated that students should be instructed to focus and primarily answer previous

questions, certainly a more difficult task than formulating new ones, which is clearly their preference. However, as it may be guessed, the best questions are those that connect Heat Transfer concepts to what I will generically call as coming from the student's background information, for instance, questions resulted from daily events, work experiences, questions from other courses (such as heat treatments, thermal tensions, welding). This has a solid basis on the Constructivist Theory (e.g. Brooks<sup>4</sup>) that suggests that better learning happens whenever new information is introduced with links to formerly acquired knowledge and clearly, such questions help a lot. Two contributions of this kind selected from last term are shown below:

- The maximum emissive power at the Sun's temperature is around 0,5 microns, which corresponds to green, instead of yellow. How come the Sun is usually painted as a yellowish disk by children?
- "I was at the beach on a somewhat cloudy day. Then, I came to think that if the clouds could be an example of a radiation shielding?"

It should be pointed out that many of those questions are incorporated to the course's FAQ file, being available for future students. Grading for such contributions considers two types of questions (reasonable and good) and three types of answers (reasonable, good and superb). Although this is a qualitative criterion, this is not a critical issue as long as the same instructor takes care of all assessments. General comments (such as administrative, general purpose and similar statements) and inquisitiveness questions are also welcome.

Similar to what occurs in many classrooms, not all students participate in the discussions with the same intensity and some do not participate at all (a.k.a. lurkers, in Internet parlance). For instance, 68% (17) of the students from last term sent more than 16 emails during the term but only 16% (4) of them sent more than 39. Considering that a term has 16 weeks, this results in one email per week for those 68% students, what is not that much of an average. That is, the standard deviation is quite large and this is certainly not good. In spite of their many reasons, such as, too many courses, work-load and others, this must be better monitored, as it is understood that many students need more time to fully understand advanced material. Emailing availability, anytime, anywhere, is very interesting, allowing students participation from many different places at odd hours, whenever they decide to participate, therefore, extending the opportunities for learning. This is a very interesting feature for many students with work-study load, a common occurrence in Brazil.

Some others, however, react differently to this, having difficulty to participate as they feel exposed to comments, criticisms and perhaps undesired jokes from other students. Actually, they have the same problem in the classrooms, indicating that shyness is an issue (in each term, roughly 20% of my students for the last two years have admitted that this is a problem). In many cases, a good private talk, in which the instructor rubs their egos a little, usually works well. As to others, a special and mutually agreed homework assignment is more suitable. In any event, many of these shy students seem to be more easily persuaded to participate online than in face-to-face classes but the important issue is that they can benefit from the collaborative environment. Unfortunately, there are those that simply choose not to participate at all. Due to the relevance of the participation of the whole group, not only for their learning but also for their final grade, more information and discussion on this should be given to the students at the beginning of the term.

As a final word on this, instructors should be aware that the number of emails have increased drastically after several terms using such conference. In the first term, back in 1999, the number of emails were in the low 300 range and in the last term, as already mentioned, they peaked at more than 1000. This is considered quite reasonable because in

spite of the extra load, as news gradually spread among the students, in each new term, more and more they come to class aware of the benefits and its importance for grading. It was also observed that gradually, the number of "junk" email generated by the students increased.

## 2.2 Heat Transfer Applets

It was quickly observed that the creation and the maintenance of simple Web pages, displaying an academic graphic design, are a very time-demanding task. After setting up the Heat Transfer site, (Braga<sup>5</sup>), students attendance (as measured by the number of hits) was noted to be lower than expected. Notwithstanding the developing effort and the availability of the site anytime, none of these factors were enough to improve students participation. Perhaps due to the fact that at that time, basically only computer versions of textbook material or printouts were available online, although colorful and with plenty of graphics and visual aids. As almost everyone will agree, reading on a computer screen is not as yet a pleasant experience, in spite of most recent LCD available. As a result, students didn't seem to benefit from the web pages, perhaps due to the lack of interaction. To overcome such low attendance, a series of interactive resources were implemented. A brief discussion on them follows.

On the Internet, interaction has several meanings, from interfaces to chats. From an educational point of view, however, interaction implies action between independent learner and computer (first step) and most important, action among learners, conducted or not through a computer. The first step was handled after the first Java interactive programs were created. At this point, many Java programs, tutorials, spreadsheets, self-evaluation quizzes with increasing complex questions were developed following Bloom's taxonomy<sup>6</sup> and frequently-asked-question files (with questions and answers raised by students from previous terms) are already available to the students in the Heat Transfer site. The implementation of these and similar features resulted in an unquestionable increase in the students participation, even when there are no examinations involved. Figure 1 shows one of the applets developed by tutor students on the understanding of energy balances on 1-D simple problems. This applet is to be used pretty much as performing a carefully conducted physical experiment. As constructivist theory suggests that questioning is the key to learning, students are initially required to investigate:

- The temperature profile considering good and poor heat conduction materials (although there is a list of materials, students are expected to understand which ones are to be selected);
- The effect of parameters such as length, thermal conductivity on the heat transfer;
- the heat transfer at both boundaries to conclude about the steady state conditions and heat balance;
- The most efficient way to guarantee that the right boundary temperature attains a specified value, say 40 C. First of all, they should come to the conclusion about the most convenient criterion to define such efficiency: heat flux or temperature and in which situation. Students are expected to find out that this may be achieved in different ways:
  - Keeping the left boundary temperature at a to-be-specified higher temperature;
  - Heating the left boundary using a to-be-specified radiative heat flux or
  - Heating the left boundary using a hot fluid having a to-be-specified temperature and with a to-be-specified convective heat transfer coefficient.

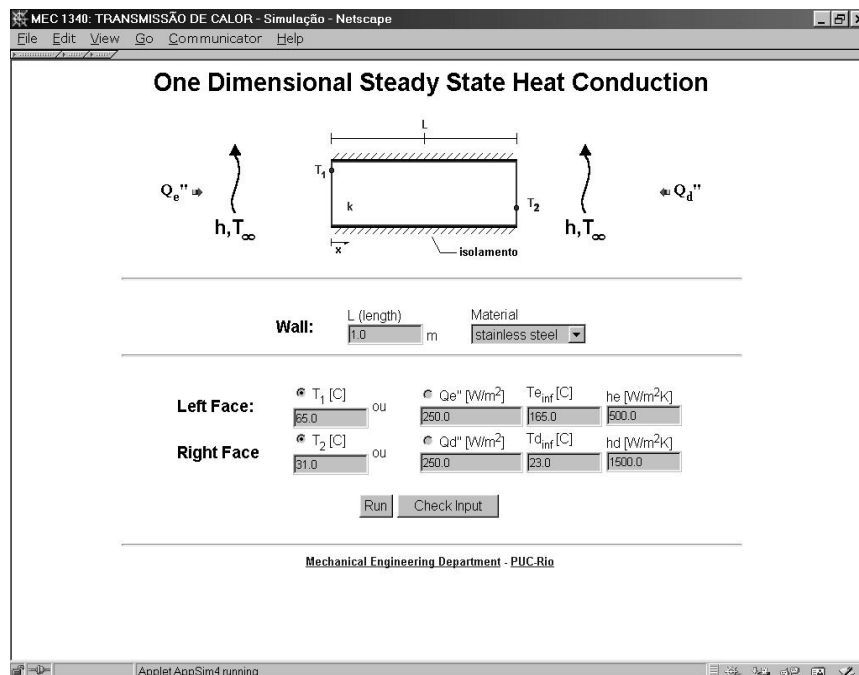


Fig. 1 One Dimensional Steady State Heat Conduction Applet, available at <http://venus.rdc.puc-rio.br/wbraga/transcal/simjava/sim4.htm> (in Portuguese)

After running such web experiments, the students are supposed to model them and then solve the problem analytically. After they have completed this task, the concrete, objective part of the learning process may be undertaken, allowing time for the constructivist approach, which demands time and deeper involvement. After mastering such a dimensional experiment, students are directed to a more sophisticated one, to analyze a more complicated thermal situation: the thermal contact resistance and its influence in the Heat Transfer between two 1-D slabs.

As it may be seen, development of similar applets is simplified through the use of templates. For each applet, a sequence of gradually more complicated questions is formulated, having the students use the applet with great care. All such experiments end with the requirement for a mathematical model for each situation. It seems that students enjoy spending time testing situations and preparing themselves for the class and Internet discussions. The experience obtained with the enhanced versions of the applets indicates that having a series of questions helps the students to overcome the barriers. Other applets are available in Braga<sup>5</sup>, some of them prepared to function as tutorials (see Figure 2). Students may take such tutorials how often they choose to but they are expected to submit a final report on each of them.

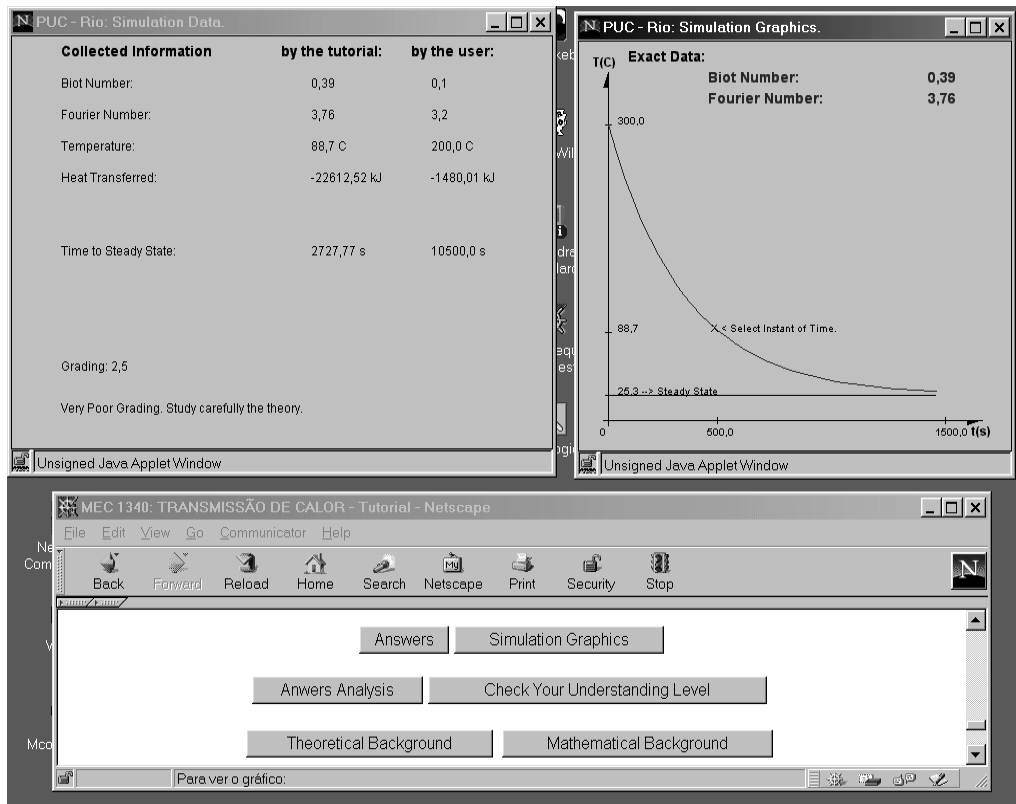


Figure 2. Display of **Answers** for a Lumped Formulation Tutorial, available at <http://venus.rdc.puc-rio.br/wbraga/transcal/tutor/tutor2.htm> (in Portuguese)

The user initially chooses the specific problem he is willing to analyze, selecting internal heat sources, material, geometries, ambient fluids and other parameters. This is done using an interface similar to the one shown in Figure 1. Next, he is asked to submit his own answers and after pressing the convenient button, the tutorial shows both answers, for assessment analysis and gives a score with a one-line conclusion. Later on, the student may press the "Answers Analysis" button to obtain a longer feedback on what he/she has (or should have) accomplished. Considering the differences found in thermal properties, for instance, due to material specifications, property temperature dependencies, convective correlations, and other sources of discrepancies in the results, the tutorial is developed to accept answers within a 10-30% range of variation, depending on the situation. In many cases, the tutorial indicates the set of data used to provoke the curiosity of students and to indicate him or her that there is not any thing such as a correct answer and at the same time giving some reasons for that. There is also an option to offer students some challenging questions on the same material in which students' theoretical understanding level may be checked by themselves.

At any time, links to the course web pages, either mathematical or heat transfer material, are available. Although not yet fully implemented, an option to generate automatically pseudo random problems is also available. This is not as sophisticated as some other questioning systems of, such as the ones proposed by Zahorian et al<sup>7</sup> or Schulze<sup>8</sup> at the present stage but offers a quicker response, besides addressing heat transfer problems.

### 3. On-site (synchronous) Classes

The methodology used is based on active learning concepts and does not differ

from others discussed in the literature. A good source of such concepts is presented by Felder<sup>9</sup> or by Wankat & Oreovicz<sup>10</sup>. The ones in use have been presented elsewhere, Braga<sup>11</sup>, and only a brief review will be discussed here, together with more recently implemented strategies. Most of the traditional academic work - first exposure to the theoretical material, simple memorizing and formula application exercises – the initial stages of Bloom's taxonomy<sup>6</sup> – must be done by the students prior to the class meeting. A previously indicated student is asked to prepare an executive summary on the next meeting material, to be distributed to other students using the same conference system previously discussed. A couple of questions on such material should also be proposed. These students are supposed to read the material, in the summary, on the Internet or in any of the books, and to solve what I have called "preparation exercises", most of the time simple exercises hopefully linked to other material. After class, that same student should propose two more questions.

In class, after turning in the preparation exercises, some of the students are asked to discuss them. They are allowed to invite another student, usually among the brightest ones, in the "most capable pal" concept, Vygotsky<sup>12</sup>. The results are usually good and promote a strong sense of responsibility and partnership among students. All such preparation exercises are graded leniently as usually students have difficulty solving them, as expected. Soon after that, more sophisticated exercises, handling the analysis and synthesis levels in Bloom's taxonomy are introduced. In fact, this stage starts with a careful reading of the exercise, done by one of them, in which the students are expected to select the important information and list it, giving them time to reflect on what they are reading, fostering text comprehension, an already understood source of problems. Experience accumulated on how we learn<sup>13</sup> indicates that experts usually see global pictures, such as governing principles, conservation laws, while naive learners tend to jump into equations. In a simple way, students should be coached on the most basic solving problem techniques.

Students are supposed to work in groups and the first group to model the problem, describe it, draw some general conclusions and win extra credits. The exercises are proposed in such a way that there is no time to "finish" them in class, requiring that the students go home and use a spreadsheet or sometimes a mathematical package such as Matlab, Maple and others to study the problem further. The results are once more distributed over the Internet.

Eventually, slides containing a brief review of the material are projected on the screen, in order to stress further some critical points already detected or even more advanced material. In the last 5-10 minutes of the class, another student previously selected at random, is asked to make a quick review on what has been discussed during that class. This is considered a very suitable time to evaluate, at least locally, what was absorbed during that meeting and how the meeting was appreciated. In many instances it was possible to correct the student's understanding, thereby perhaps helping others.

For two terms, I tried to use a computer room in order to mix both environments further. After that period of time and some 60 students later, I gave up. It was literally impossible to prevent students from navigating throughout the Internet, tying them to the Heat Transfer site. The lack of a security software was the culprit, for sure, but it is not clear anymore that the benefits from a fully online course may overcome the complexity of having a large number of students navigating through a large number of different pages, even if they are all from the same site, and asking questions on material covered on such pages. This may easily turn into a disaster, pedagogically speaking. Actually, having them follow the leader, I mean, the teacher on a rigid sequence of screens seems most likely to return to a rigid methodology in which the teacher, once again, is the only responsible for the learning. This looks too similar to that standard teaching technique in which most of us, instructors,



were taught to be copied by the students. The teacher is in the spotlight, that is writing down all the material on the blackboard or solving extensively a set of exercises close to an examination while the students watch passively. It is simply too rigid for present day needs. In any event, the students response and the course assessment are indicating that the combination of on-site classes and the Internet are working well, with no need for special rooms, at least so far.

#### 4. Challenging Problems

In order to induce open questioning from students and hopefully motivate bright students for advanced studies in Heat Transfer, two or three challenge problems are proposed each term. Due to their apparently simplicity as something they may observe daily, students are easily motivated to analyze them. As they deal with Convective and Radiative modes of Heat Transfer, they have a non linear nature and should be solved using some math package. Examples of recent problems are given below:

- Suppose that an apple pie is mistakenly delivered at the Office of the ME Department. The pie's diameter is 0,40 m and 0,15 high. It is hot, at some 75 C. The pie is being expected at the Chem. Eng. Office, located at the end of the hall. It should be delivered in one piece, using a delivering cart, driven steadily without accelerations. By the time it gets there, however, someone notes that a significant piece is missing and the suspicious is the Faculty of the ME Department, i.e. one of the many professors with offices located at the same hall. The **Heat Transfer Class** is required to find out the responsible. Can it be done?
- Consider a cup of coffee with a spoon in it. The coffee is at some 75 C while the ambient temperature is 28 C. What is the influence of the submersed length of the spoon in the coffee on the cooling rate of the coffee? To maximize cooling, which should be the submersed length?

For such problems, group work is strongly recommended and comparison with experiments is suggested. As students have to consider all three modes of heat exchange, such problems are far from being just simple exercises.

#### 5. Course Evaluation

Traditionally, ME 1340 Heat Transfer is considered a difficulty course at PUC-Rio and, not surprisingly, the final grades are not very high. However, since a couple of years ago, students' learning seems to have been improving, at least if one considers those students that prior to the final exam managed to have already passed. That is, a now significant number of students are being able to complete the course requirements (a minimum final grade of 5 points on a 10-point scale), without taking the exam, although it is a mandatory one. Table 1 indicates how this percentual number has changed during the last years. Considering that at no point easier mid term tests were intended to be given, these results are interesting. This certainly is indicative of a better and more experienced handling of IT resources in the overall environment. Hopefully, something else can also be learned, even considering that such numbers do depend on many factors. An extended analysis will be discussed elsewhere<sup>14</sup>. In any event, these results induce encouragement, at least.

Table 1. Number of Students passing without taking the final exam

Term	Total Number	Number	%
1998.2	26	2	7,7%
1999.1	17	0	0,0%
1999.2	30	9	30,0%
2000.1	31	20	64,5%
2000.2	22	12	54,5%
2001.1	34	10	29,4%
2001.2	25	13	52,0%

## 6. Cheating

This is one of the problems we are all facing. In the past, cheating was somewhat restricted to examinations and was something students shared among themselves. These days, cheating has a much wider context, as it encompasses Internet in the sense of the so many sites where students may obtain reports, projects, and so on. For instance, the number of questions students submit to my HT site is enormous. Recently, Harding et al<sup>15</sup> presented an extended analysis on the state of research on academic dishonesty, that deserves to be read with great care. Besides subscribing to most of those observations and conclusions, I should add that this is not a major problem in my course as limited time and extensive analysis requirements on all written examinations do not allow much time for such. For other assessment and evaluation resources, the most successful technique I've implemented is to consider them on a competitive basis. Students may or may not return them but only the best reports (or those from the first group to return) are considered. Knowing that all of them may be invited to give oral presentations on what they have done, ensures at least, I understand, that they will study it. In the handout distributed to the students in the first class, there is clear indication that cheating is not accepted, under any circumstance. The policy is to prevent it before it happens. However, cheating seems to be something many instructors allow and in fact, some instructors do so.

## 7. Conclusions

In this paper, several strategies for enhancing engineering education were indicated, although developed for a Heat Transfer course. The whole idea is to intermix on-site classes with the Internet in order to extend the exposure time to the subject. The focus is clearly on the use of collaborative work, most of the time, in order to support knowledge construction. The overall teaching load has significantly increased, mainly due to the use of an online conference system, in which classes continue at odd hours, depending on the students. This availability generates more than one thousand emails during a single term, with all indications that this number may increase. As all of them should be read, to give follow up, feedback, and eventually to draw conclusions from many different contributions, a managing system should be implemented. The results however indicate that students benefit from such efforts, as they feel less intimidated by the instructor and enjoy the new challenges provided by a different way of teaching, with more space for open discussions instead of the usual right (instructor) or wrong (students), binary way of teaching. The instructor may also enjoy the challenge of teaching differently each term.

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## Biography

WASHINGTON BRAGA is a professor in the Mechanical Engineering Department at The Catholic University of Rio de Janeiro, PUC-Rio, Brazil. He is involved in Engineering Educational research, developing methodologies to couple on-site and online classes. He is the author of two Heat Transfer undergraduate textbooks that implement his conclusions concerning collaborative work and Internet.