International Journal of Engineering Education Vol. 29, No. 2, pp. 510–519, 2013
Printed in Great Britain
0949-149X/91 $3.00+0.00

Teaching Computer Architecture using a Collaborative Approach: The SIENA Tool, Tutorial Sessions and Problem Solving*

LORENZO MORENO, CARINA GONZÁLEZ, EVELIO J. GONZÁLEZ, BEATRICE POPESCU and CLAUDIA O. L. GROENWALD[1]

Departments of Systems Engineering and Automation, and Computer Technology and Architecture, Av. Astrofísico Fco. Sánchez S/N, CP 38206, Universidad de La Laguna, Tenerife, Spain

[1] Faculty of Mathematics. Postgraduate course *The Teaching of Sciences and Mathematics*, Universidade Luterana do Brasil, Brazil.
E-mail: ejgonzal@ull.es

This paper presents a teaching–learning methodology that combines Blended Learning (BL) and Computer-Supported Learning (CSCL). We have created a tool called SIENA that assists students with self-learning. The SIENA tool uses conceptual maps and adaptive testing to guide the learning process of students working together in small groups. The tests, which include functions that are specifically suited to online collaborative work, use teaching–learning materials and questions that have been developed in collaboration with final-year students taking the subject Computer Architecture.

Keywords: higher education; blended learning; continuous assessment; collaborative learning; adaptive tests

1. Introduction

The European Union (EU) recently established the European Higher Education Area. With this move, the EU wants to ensure that all higher education programs across Europe are on an equal footing, thus improving student mobility and employability, lifelong learning opportunities, and also the competitiveness and quality of universities in the EU. What this actually means is that all European universities now find themselves facing the challenging questions of how to develop more transparent study programs, and how to improve the quality of their own programs. This context provided us with the opportunity to question whether any adaptations or improvements could be made to how we were delivering different subjects to our own students.

What was clear from the start was that we wanted to provide a methodology and tool that could help teachers to perform continual assessment: we believe that it allows teachers to evaluate their students' understanding and abilities better than does a single final exam, and that students also learn better if they are given the opportunity to retake failed tests. The only problem with continuous assessment is that it is often based on subjective reasoning, rather than on the use of objective data, so we would also need to overcome this limitation.

We identified that we should be trying to provide a tool that: a) facilitates the assimilation of concepts by students, b) increases motivation amongst students, c) allows teaching staff to monitor and access student performance and participation, and d) improves the objectivity of information available to teaching staff regarding their students' performance and participation. With this last point, we want to ensure that the continuous assessment process is made more objective, and thus ensure that the quality of the course can be reproduced year after year, or at other EU universities. Based on these ideas, we propose incorporating new technologies in the classroom and combining them with innovative teaching methods to improve the teaching–learning process. This paper presents our proposed methodology and our conclusions regarding its performance.

Our proposed methodology focuses primarily on the use of Blended Learning, which consists of simultaneously delivering both classroom-based activities and distance learning and self-evaluation on the part of the student. However, it is worth noting that BL also includes a strong collaborative aspect, as will be seen later on. For the purposes of our research we have designed a tool for our students to use when working together in small groups. This tool has been designed for autonomous learning and to guide the learning process through the use of conceptual maps and adaptive tests. It also provides the teacher with personalised information on each student's progress. The adaptive tests include functions specifically suited to online collaborative work. The tool is called SIENA.

We tested our methodology on students studying Computer Architecture. This subject is one of the last subjects to be offered as part of our Computer Engineering course. As these were final-year students they demonstrated an intellectual maturity

* Accepted 14 November 2012.

(having completed Computer Structures, Operating Systems, Network Switches, etc.), which made it possible for us to evaluate and refine our tool and materials by collaborating with them on the following:

- Content creation and content searches
- The creation of questions that are then incorporated into the adaptive tests that are used during self-evaluation (details of which are presented further on)
- The validation of different tools such as simulators and SIENA.

Section 2 of this paper contains details of the fundamental basics of our methodology and its key pedagogical aspects. Section 3 provides an overview of the Computer Architecture course and its modules. Section 4 contains the methodology used and details of the SIENA tool—how SIENA was developed, how it is used for group learning, how it is used for continuous assessment, how simulators can be used for problem solving—and we present details of the experiment carried out. In the final sections, we present an analysis of the results of our experiment and present feedback from both staff and students regarding their experiences of using our methodology. Lastly, we present our final conclusions.

2. Overview of BL and CSCL methodology

The Blended Learning (BL) approach is a teaching and learning strategy that has been successfully applied across a range of different situations [1]. Table 1 illustrates the advantages (reinforced in the BL approach) and disadvantages (mitigated by the BL approach) of face-to-face learning and distance learning [2–10].

We use Computer-Supported Collaborative Learning (CSCL) to complement the BL approach. The use of CSCL can facilitate group learning. It can also facilitate learning in which the communication process is produced bi-directionally between people with different roles, i.e. professors and students [10]. This kind of collaborative strategy requires more social interaction and student participation than traditional methods. However, it has been demonstrated that the collaborative effort involved during the learning process results in a more thorough assimilation of concepts and better knowledge building [11]. These strategies depend on a student-centred learning process [10]. For this to work, it is essential that teachers are still able to monitor, assess, and assist students whilst they work individually or in groups [10–16].

One of the key aspects of our proposal is to increase student motivation. We aim to achieve this in four ways [17–24]:

- by increasing student self-esteem and autonomy. traditional strategies tend to be based solely on the binary 'reward/punishment', which is more focused on the results of an assessment than on the learning process itself [25];
- by avoiding repetitive activity patterns in class;
- by making the student aware that his/her learning requirements are connected to the educational environment;
- by designing online activities using systems that

Table 1. Advantages and disadvantages of face-to-face learning and distance learning (adapted from [8])

	Advantages	Disadvantages
Face-to-face learning	Sense of belonging to a group, which in turn serves to encourage confidence felt towards teaching staff Quick creation of inter-connected ideas. Quick discoveries through guessing It is possible to carry out more complex tasks	Not all students are able to participate, especially when there are more dominant personalities in the classroom Time limitations: it is not always possible to go into as much detail as is desired during debates for fear of running out to time
Distance learning	Enables cooperative and collaborative learning Improves active participation Participation does not depend on the surroundings or on timeframes Low cost The student is able to dedicate more time to the activity if necessary Exams and exercises can be done online Flexibility in completing the subject syllabus	Poor in terms of social communication (self-study, this method is considered impersonal . . .) Initial set up requires time and effort Access may be affected due to possible log-in problems Launching it may require a multidisciplinary team Limits the development of associations via idea strings, or of discovery through guessing Tendency towards producing excess content Higher student dropout rates are more likely Possible tendency towards apathy and the postponement of activities

Table 2. Course syllabus—main units, subjects and topics of Computer Architecture

Units	Subject	Topics
Introduction	Design fundamentals.	Performance measurements. Design of instruction repertoires: Microcontrollers, Embedded systems, Digital signal processors. General-purpose processors
Techniques for increasing performance I	Processor segmentation.	Type of dependencies. Anticipation technique. Exceptions. Delayed jump. Segmentation of operational units. Simulators.
	Vector processors.	Operational units. Load unit/storage unit. Compilation techniques. Simulators.
Techniques for increasing performance II: dynamic and static approaches	Instruction Level Parallelism (ILP).	Superscalars: Tomasulo algorithm. Dynamic control of branches. Types. VLIW/EPIC processors: Predicate registers, Compilation techniques. Simulators.
Thread level parallelism	Multi-threading and Simultaneous multi-threading.	Characteristics: Fine grained and coarse grained. Example architecture: Niagara, Montecito . . .
Memory hierarchy	Virtual memory and cache.	Types. Page tables. Organisations. Top down/Bottom up traversal of page tables. TLB. Replacement algorithms. Cache memory organisation. Techniques for improving cache performance. Coherence. Simulators.
Interconnection networks	Basic definitions. Organisational structure.	Bandwidth and latency. Network .switch. Classification of interconnection networks.
	Direct networks.	Characterization. Topologies.
	Indirect networks.	Characterization. Topologies.
	System buses.	Hyper-transport.
Multi-processor Architecture	Multicore, Manycores, Shared Memory, Scalable multi-processor.	Coherence: Snooping, directory. Synchronization. Graphics and computing GPUs.

do not merely transfer the classroom-based activities into a virtual format.

3. Computer architecture: an overview

We felt that this subject was ideal for testing our methodology because simulators are often used in this subject. Students create these simulators as part of their final thesis [26–28]. These simulations are designed to improve the understanding of complex problems. In Table 2 we provide details of the course. It is from this content that we create the conceptual maps that are used in adaptive testing.

4. Methodology

Students are told to organise themselves into groups (with a maximum of 2 or 3 students per group). Students are instructed to work on course content: they must use the information provided to them by their teacher, i.e. theoretical notes, practical exercises carried out on simulators, proposed exercises, and extra reading materials (books, magazines, websites, etc.).

Students are also instructed to a tool called SIENA that is designed to assist them with self-study and self-evaluation. This tool also allows teaching staff to personalise tutorial sessions. It provides objective data on student participation and performance that can be used by the teacher to provide accurate feedback and an objective grading system for continuous assessment.

Students may be asked to work individually, or collaboratively—this could be within their group, or each group may be required to work with the other groups. SIENA is able to monitor an individual student's work, whether it is produced alone or during collaborative tasks.

In the following sub-sections, we discuss each of the elements of our proposed methodology in detail.

4.1 The SIENA tool

The Integrated Teaching–Learning System (SIENA) has been created to help students with self-study and self-evaluation [29–30]. SIENA must be used together with a tool called Compendium. We use the Compendium tool to create a conceptual map of the subject, Computer Architecture. Once created, we open SIENA and import the map from Compendium. This conceptual map is based entirely on a relationship of knowledge: the nodes on the map are the topics of the subject, and the connection between these nodes is such that if topic B connects to topic A, then to understand B correctly a student must first understand A.

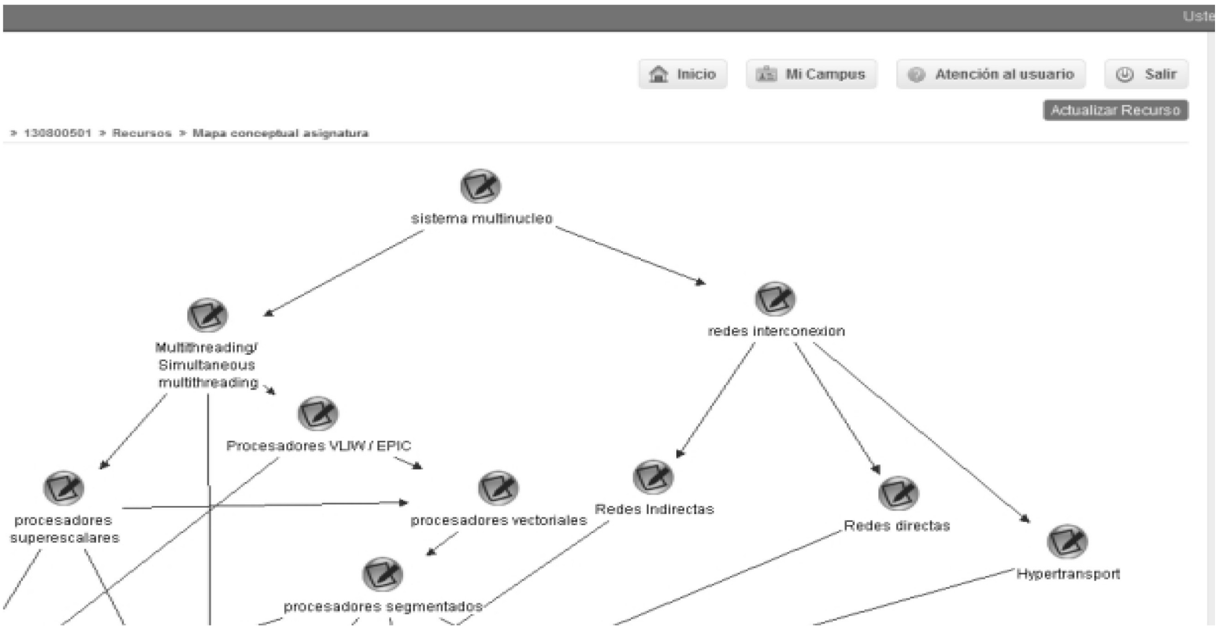

Fig. 1. Example of a conceptual map designed using Compendium (detail).

To illustrate this we have provided a conceptual map from the subject in Fig. 1. The nodes of this subject are the *topics* that make up the subject. These nodes are connected through a relationship of knowledge; for example, if a student wants to start to study *Multicore Systems,* the student must first have understood the nodes *Interconnection Networks* and *Multi-threading Systems andSimultaneous Multi-threading*.

The SIENA tool includes an adaptive test containing multiple-choice questions for each of the nodes on the conceptual map (this is in addition to the node content). These tests have been implemented using Bayesian networks [31]. These networks connect the concepts of the map to the questions. This allows the adaptive test to estimate a student's knowledge, which it does by using the answers that students give to each of the subsequent questions presented by the tool.

SIENA works by:

- *Selecting the 'target node'*: Students follows the self-study content and complete the tests presented for each node by the SIENA tool until they reach the target node. The target node is the node that the student should reach by correctly applying previous knowledge. If the students have not assimilated enough knowledge to pass a specific node then the tool will prevent students progressing further. However, the tool does allow students to explore alternative routes by presenting them with alternative nodes if this happens.
- *Calculating understanding*: When a student answers a question on any given node, the adaptive test uses Bayes formula to calculate a student's posterior knowledge. This formula uses three parameters: the student's a priori knowledge, difficulty (probability of correctly answering the question supposing that the idea is understood), and guessing (probability of correctly answering the question supposing that the idea is not known).
- *Selecting a new question*: The next question, which is selected from all the remaining questions associated with the node, is chosen to maximize an objective function.

The test ends if the difference between the estimated knowledge is no greater than 0.01 for the last five questions, or there are no more questions.

Figure 2 shows the data for a question with all of its parameters, and Table 3 contains an example of the test results that are visible to both the professor and to the group of students.

4.1.1 *How the test questions were developed*

The conceptual map produced for Computer Architecture consists of fifteen nodes and holds approximately 1500 questions. The academic staff worked in collaboration with the final-year students to select the topics and content used in SIENA. The questions themselves were written by the students and refined with feedback from the academic staff. The process of constructing and validating the entire volume of questions has taken three academic years.

Our students needed to make significant efforts with regards to their own learning in order to prepare the questions for each node of the conceptual map. To assist their efforts, the teachers regularly met with the groups to discuss the questions

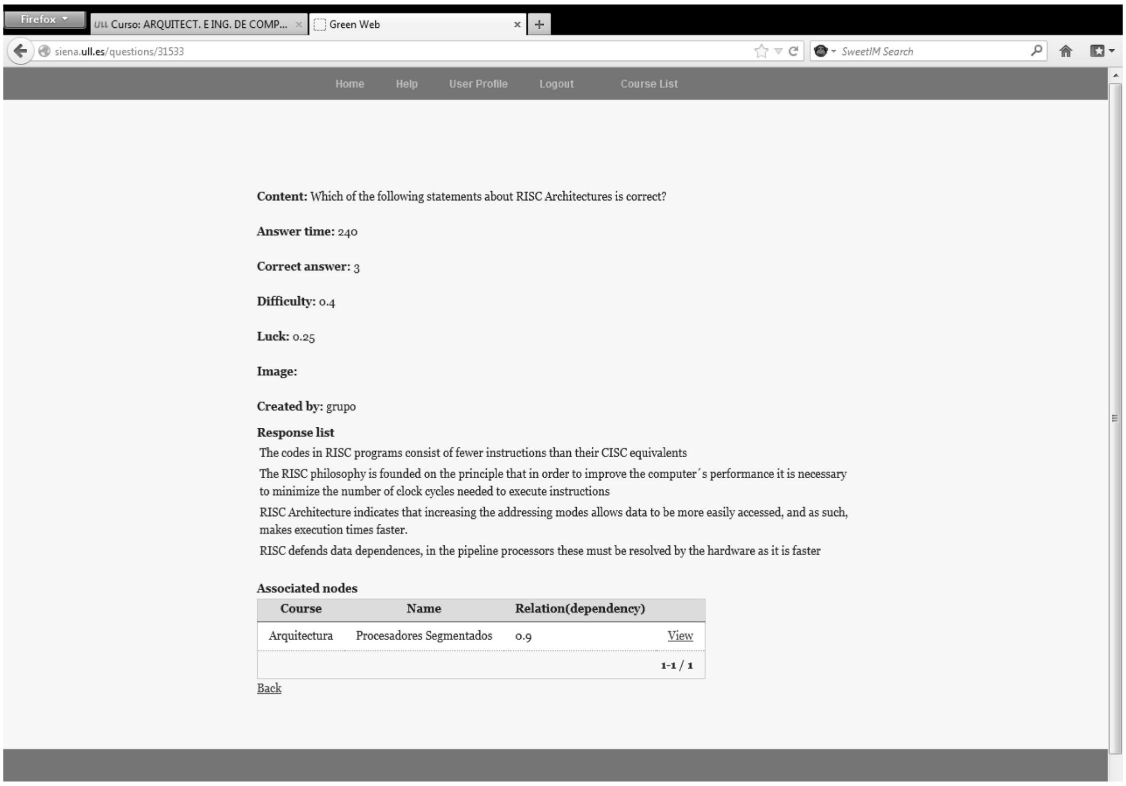

Fig. 2. Configuration of a question in SIENA including all its parameters.

being proposed by students, and any difficulties they encountered—not only with the subject, but also during the collaboration process. The teacher provided feedback, which included: suggestions for new questions; comments on the difficulty of the questions already created; and proposals for new strategies to improve the collaboration efforts, etc. The teacher also provided the students with additional material.

Each group has to select a node on the conceptual map. Once they have done so, they are then responsible for creating the content for this topic and designing the test questions. During this process students have to try to follow the IP model (Progressive Inquiry) [16]. Students need to use Moodle to organise and coordinate all the work that is carried out by the group and its individual members.

All aspects of progressive inquiry, such as the creation of research questions, the search for new scientific information, building their own working theories or assessing the explanations have to be shared with other participants during the learning process. This is the last phase of the questioning process, which we refer to as 'knowledge sharing'. This phase consists of explaining a problem to other participants: this is one of the most important competencies of the *European Space of Higher Education*, and one of the key aspects of the management model of collaboration.

4.1.2 Incorporating the online collaborative work strategy into SIENA

An additional function has been added to the SIENA tool that allows it to perform synchronous

Table 3. Test results (Example)

Answer	Correct Answer	Time (before running out)	Question	Points before	Points after
3	true	961	Which type of vector instruction fits the following definition: 'Instructions in which the operations are vectors and the result is a scale'	0.300	0.340
1	true	16	The start-up time for register–register operations (in clock cycles) is:	0.340	0.507
2	true	901	What happens if the longitude of the vector operation is unknown during compilation and, in addition, may be greater than the maximum longitude of the vector (MVL)?	0.057	0.787

communication (chats) during the online collaborative tests. This new tool is called SOCIAL SIENA. The chat feature records the messages sent between the group's members. These messages can then be read, assessed, and deleted by the teacher, and read by the students. The purpose of this function is to give the teacher an objective analysis of each student's participation whilst he or she answers the questions presented in the adaptive test, and thus provide better continuous assessment.

4.2 Tutorial sessions: continuous assessment

Students are able to complement classroom-based content in three ways:

1. by using the content stored in each node of the conceptual map in SIENA;
2. by using multimedia knowledge pills (audio-visual clips between 5 and 10 minutes long that are designed to educate following the IMS LOM standard);
3. by carrying out the self-evaluation test/s in groups.

Once a student completes a node on the conceptual map, the professor holds a tutorial session for the group in order to analyse the questions and answers that were submitted. These tutorial sessions give the teacher one-on-one time with the student and, thus, an opportunity to establish the individual knowledge of each of the group's members. They allow the teacher to: clearly identify any possible gaps in knowledge; provide information about said gaps; respond to questions relating to these gaps; and, most importantly, they help the student to progress. These sessions ensure that each student is aware of his or her own progress, and what he or she needs to do to improve the learning process.

The tutorial session is an essential pillar of collaborative learning, especially in the case of large groups of students. These sessions strengthen the collaborative learning process and play a key role in the context of continuous qualitative improvement of higher education courses.

4.3 Problem solving

For innovation purposes, our methodology also includes the additional task of problem solving. We use tasks involving simulators in which we reproduce all of the transversal competencies mentioned in Section 4. Students tackle problems relating to the main conceptual map nodes—such as the superscalar processors and VLIW/EPIC processors—using the SIMDE simulator [29]. This simulator allows a program to be run in MIPS code in one of two ways: it may either use dynamic planning based on the Tomasulo algorithm including reservation stations, reorder buffer and a bimodal predictor for conditional jumps (superscalar processors), or it may use static planning that uses Very Long Instruction Word VLIW/ Explicitly Parallel Instruction Computer EPIC processors.

Problem solving covers individual, intra-group, and also inter-group work. The results our students obtain have to be submitted in writing and also delivered as an oral presentation to the rest of the class. We use Moodle to track each student's activity. A task is created on the Moodle platform and the entire process is recorded from start to finish. The information provided by Moodle finally forms part of the continuous assessment process.

4.3.1 The experiment

The different groups of students were presented with five randomly selected exercises, following the scheduling shown in Table 4. The exercises involved generating a code and optimising it on a superscalar machine and on a VLIW machine via the SIMDE simulator.

4.3.2 Results and analysis of experiment

A total of twelve groups were created. Of these twelve, ten did the work that we set them and followed our instructions precisely. However, one of the groups did not do the work, and another group did it incorrectly. In this last group, the group members completed the work they were told to do in groups and also for presentations, but the students failed to do the individual work required of them. They also failed to deliver their presentation within the stipulated timeframe.

We found that our methodology produced interesting collaborative work between the students. We were able to follow the individual creative efforts by students. We noticed significant involvement on the part of the students, and a renewed level of interest in the subject matter. This is relevant because this motivation was not present in previous years when this methodology was not part of our teaching policy. Generally, we have seen an improvement in the quality of the presentations and students appear to be more confident when they present their optimised codes. Encouragingly, we have also noticed greater dedication to the problem that they are set. And, finally, we have found that the students themselves have been extremely honest when putting forward the best optimisations obtained by their group, or by other groups.

5. Student feedback

We continue our research by asking our students for feedback regarding our proposed methodology, asking them to assess its suitability for use in continuous assessment. Twenty-four students of

Table 4. Type of work performed by each group

Type of group work	Task description
Individual work between the members of the group	Create a base code. Each member of the group then has to optimise the problem's code by using appropriate techniques—this normally involves reorganising the code, unrolling the loops, planning, segmentation software, trace scheduling, etc.
Intra-group work	The members of the group should decide between themselves how to optimise the code they have produced.
Inter-group work	Students must decide how to optimise the code, but instead of working with members of their own group, they must collaborate with the other groups that are working on the same problem.
Oral presentation	The groups deliver a 20–30 minute presentation to the rest of the class. Each member of the group explains what their own optimisation consists of. Students conclude their presentation with the group stating the best optimisation choice from all those proposed within the group. The last group to deliver a presentation presents the best optimisation from the work of all the groups who have carried out the same task. The optimisation is objectively chosen, based on its performance.

Computer Architecture participated in the survey (see Table 5). The survey used a Lickert-like questionnaire in which students indicated their level of agreement or disagreement with a series of statements [32].

We concluded our survey by asking our students two open questions about SIENA:

1. Should it include other functions or features?
2. Could the questions and/or answers be improved in any of the nodes?

From these two questions, we found that the students share the opinion that SIENA should inform them of the correct response when a question is not correctly answered. The teachers, on the other hand, think that students should not be shown the correct answer. Our teachers believe that this process of trial and error will lead to a better understanding of the subject matter as it will oblige students to return to their books (so to speak), and to revise the theory again. Students will eventually arrive at the correct answers to the questions using this technique and they will retain the information better than if they were spoon-fed the correct responses.

In general, the results confirm that a larger percentage of students either agree or totally agree with using tutorials to support the continuous assessment process.

In addition, we have found that tutorial sessions can be used to increase motivation. By informing students that the tutorial sessions will cover the content included in the test/s they feel obliged to complete the work they have been set. Students are aware that this content will be covered in the tutorial sessions and the majority ensure that the tests are completed on time.

Not only do the sessions encourage students to be better prepared, but they are also used as a feedback tool that assists students in improving the grades they obtain. Using tests directly after studying the content of a course is a method that allows students

Table 5. Responses to the questionnaire: 'Degree of satisfaction with the proposed methodology'

Statement	Strongly disagree (1)	Disagree (2)	Maybe (3)	Agree (4)	Strongly agree (5)	Average
The tests for each of the nodes of the conceptual map have been a useful learning tool.	–	–	16%	57%	27%	4.29
The content of each node has helped me to prepare the subject and take the corresponding node test.	–	–	12%	71%	17%	4.04
SIENA is a suitable learning tool.	–	–	17%	53%	30%	3.96
The strategy of taking tests in collaboration is more suitable than taking them individually.	–	7%	16%	32%	45%	4.20
The strategy of taking tests and having tutorial sessions that deal with the content of the tests is a suitable assessment method.	–	–	17%	42%	41%	4.25

to have an early indication of their marks and reflect on how well they understand the content being studied, the tutorial sessions then put them on the right path should they be having any problems with the content of the course.

6. Conclusions

Our aim was to improve the teaching–learning process. To do so, we chose to incorporate new technologies in the classroom—SIENA + SIENA SOCIAL functions and Moodle—and combine these with the Blended Learning method. We used SIENA to facilitate the assimilation of concepts by students, and we used tutorial sessions together with this tool to increase motivation amongst students; we also provided our teaching staff with the tools that allowed them to monitor and access student performance and participation and, most importantly, obtain objective information regarding their students' performance and participation, thus improving the quality of the continuous assessment process.

We created experiences that are not merely extrapolations of classroom-based activities, but that were especially conceived for the virtual environment. Using SIENA, we provided students with a tool that creates a feedback loop that improve self-study. As such, our proposed methodology contributed to the development of the transversal competencies. In addition, we were able to increase the collaborative effort amongst students by setting group-based tasks, such as the problem solving activity detailed in Section 4.3.

The limitations that we encountered when using our methodology were that a) it requires a significant amount of time to create the materials for the course, b) it requires a significant amount of time to update materials as theories advance, or to create new content for students who are repeating the course, and c) it requires a significant amount of effort to manage on a day-to-day basis because of the continuous assessment factor. So, in general, the teaching staff will have to dedicate themselves wholeheartedly if they use this methodology. However, any stress this may create is certainly compensated for when you witness increased motivation and improved learning amongst your students.

In response to the second limitation, we aim to improve the quality of our teaching–learning materials for future courses by:

- Configuring the context: improving the questions relating to the topic, or validation of situations, or real-life problems
- Increasing the number of questions: improving the randomised selection process
- Updating content: including questions relating to cutting edge technologies, such as: embedded systems—Arduino system, Raspberry Pi; Sloppy chips, etc.
- Creating working theories: producing conjectures, hypothesis, theories or interpretations of the problems being studied; likewise, intuitive concepts should be explained and externalised (for example, writing about any preconceived ideas held about a problem or topic being studied)
- Carrying out critical assessment: evaluating the strengths and weaknesses of the different explanations and identifying contradictory explanations, knowledge pools, and the limitations of an intuitive explanation
- Pursuing knowledge: researching new information relating to the problem being studied
- Developing problems: researching deficiencies and/or limitations, raising questions and theories that can guide further research.

Although this methodology has been applied to the subject Computer Architecture, we would like to state that it could easily be applied to any subject being offered as part of a degree in Science or Engineering. We are confident that the continuous assessment process has been made more objective, and that it thus ensures that the quality of the course can be reproduced year after year, or at other EU universities should they wish to adopt it.

References

1. I. Clark, and P James, Blended learning: an approach to delivering science courses on-line, *UniServe Science Blended Learning Symposium Proceedings*, 2005
2. S. Rouvrais, P. Maille, J. Gilliot, G. Madec and A. Guyomar, Migrating learn-by-doing engineering curricula to blended learning. In P. Kommers and G. Richards (Eds), *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2005*, 2005, pp. 4053–4058.
3. R. Garrison and H. Kanuka, Blended learning: uncovering its transformative potential in higher education, *The Internet and Higher Education*, **7**(2), 2004, pp. 95–105.
4. B. Collis, H. Bruijstens and J. Kees Der Van Veen, Course redesign for blended learning: modern optics for technical professionals, *International Journal of Continuing Engineering Education and Lifelong Learning*, **13**(2), 2003, pp. 22–38.
5. A. J. López Martín, Web-based remote learning of communication systems: a successful experience, *International Journal of Electrical Engineering Education*, **40**(3), 2003, pp. 169–174.
6. J. A. Méndez and E. J. González, Implementing motivational features in reactive blended learning: application to an introductory control engineering course, *IEEE Transactions on Education*, **54**(4), 2010, pp. 619—627.
7. J. A. Méndez and E. J. González, A reactive blended learning proposal for an introductory control engineering course, -*Computers & Education*, **54** (4), 2010, 856–865.
8. C. J. Bonk and C. R. Graham (Eds), *Handbook of Blended Learning Environments: Global Perspectives, Local Designs*, Pfeiffer Publishing, San Francisco, CA, 1998.
9. Alfred P. Rovai and Hope M. Jordan, Blended learning and sense of community: A comparative analysis with traditional and fully online graduate courses, *International Review of Research in Open and Distance Learning*, **5**(2), 2004, pp. 1–13,

10. A. Soller, P. Jermann, M. Mühlenbrock and A. Martinez, Designing computational models of collaborative learning interaction, *Introduction to the Workshop Proceedings, ITS 2004 Workshop on Computational Models of Collaborative Learning*,August 31, 2004 Maceió, Brazil, 2004.
11. P. Jermann, A. Soller and A. Lesgold, Computer software support for CSCL, In P. Dillenbourg (Series Ed.) and J. W. Strijbos, P. A. Kirschner and R. L. Martens (Vol. Eds), *Computer-supported Collaborative Learning: Vol 3, What we know about CSCL . . . and Implementing it in Higher Education*, Kluwer Academic Publishers, Boston, MA, 2004, pp. 141–166.
12. P. Dillenbourg, M. Baker, A. Blaye and C. O'Malley, The evolution of research on collaborative learning. In P. Reimann and H. Spada (Eds), *Learning in Humans and Machines: Towards an Interdisciplinary Learning Science*, Elsevier, Oxford, 1995, pp. 189–211.
13. P. Jermann, A. Soller and M. Muehlenbrock, From mirroring to guiding: a review of state of the art technology for supporting collaborative learning, *Proceedings of the First European Conference on Computer-Supported Collaborative Learning*, Maastricht, The Netherlands, 2001, pp. 324–331.
14. H. Shih, Using a cognition-motivation-control view to assess the adoption intention for Web-based learning, *Computers & Education*, **50**, 2008, pp. 327–337.
15. H. Ogata, K. Matsuura and Y. Yano. Active knowledge awareness map: visualizing learners activities in a web based CSCL environment, *International Workshop on New Technologies in Collaborative Learning, Tokushima*, Japan, 2000.
16. J. T. Schmidt, Preparing students for success in blended learning environments: future oriented motivation and self-regulation, edissertation, LMU Munich, Faculty of Psychology and Educational Sciences, 2007.
17. P. R. Pintrich and B. Schrauben, Students' motivational beliefs and their cognitive engagement in classroom tasks. In D. Schunk and J. Meece (Eds), *Student Perceptions in the Classroom: Causes and Consequences*, Erlbaum, Hillsdale, NJ, 1992, pp. 149–183.
18. R. J. Wlodkowski, *Motivation and Teaching*, Washington, D.C.: National Education Association, 1991.
19. T. M. Green and C. M. Kelso, Factors that affect motivation among adult learners, *Journal of College Teaching & Learning*, **3**(4), 2006.
20. D. J. Lynch, Motivational factors, learning strategies and resource management as predictors of course grades, *College Student Journal*, **40**, 2006, pp. 423–429.
21. V. P. Richmond, Communication in the classroom: power and motivation, *Communication Education* **39**(3), 1990, pp. 181–195.
22. J. M. Keller, Motivational design of instruction, In C. M. Reigeluth (Ed.), *Instructional Design Theories and Models*, Lawrence Erlbaum Associates, New York, 1983, pp. 383–433.
23. D. Christophel, The relationships among professor immediacy behaviors student motivation and learning, *Communication Education*, **39**, 1990, 323–340.
24. Z. Dornyei, *Teaching and Researching Motivation*, Longman, Harlow, 2001.
25. R. H. Shroff and D. R. Vogel, Assessing the factors deemed to support individual student intrinsic motivation in technology supported online and face-to-face discussions, *Journal of Information Technology Education*, **8**, 2009, pp. 59–85.
26. L. Moreno, E. González, B. Popescu, J. Toledo, J. Torres and C. González, MNEME: A memory hierarchy simulator for an engineering computer architecture course, *Computer Applications in Engineering Education*, **19**(2), Wiley, 2011, pp. 358–364.
27. L. Moreno, C. González, I. Castilla, E. González and J. Sigut, Applying a constructivism and collaborative methodological approach in engineering education, *Computers and Education Journal*, **47**(3), 2007, pp. 891—915.
28. L. Moreno, C. González, I. Castilla, E. González and J. Sigut, Use of constructivism and collaborative teaching in an ILP processors course, *IEEE Transactions on Education*, **50**(2) 2007, pp. 101–111.
29. L. Moreno, C. González, R. Estévez and B. Popescu, Intelligent evaluation of social knowledge building using conceptual maps with MLN, *4th International Conference on Educational Data Mining*, Eindhoven, 2011.
30. L. Moreno, C. González, E. González, B. Popescu and C. Groenwald, Supporting the autonomous learning process with SIENA, *CSEDU* (1) 2009, pp. 452–455.
31. E. Millan, J. L. Pérez de la Cruz and F. Triguero, Using Bayesian networks to build and handle the student model in exercise base domain in lecture notes in computer science, Vol. 1452, *Intelligent Tutoring Systems Proceedings of the 4th International Conference ITS'98*, Springer Verlag, Berlin, Heidelberg, 1998, p. 612.
32. H. Muukkonen-van der Meer, Perspectives on knowledge creating inquiry in higher education, Doctoral dissertation, University of Helsinki, Institute of Behavioural Sciences, Studies in Psychology, 75, Helsinki University Print, Helsinki, 2011.

Lorenzo Moreno received his MS and Ph.D. degrees from the Universidad Complutense de Madrid, Spain, in 1973 and 1977 respectively. From 1977 to 1979 he was an Associate Professor in the Department of Computer and Control Engineering, Universidad del País Vasco, Spain. From 1979 to 1988 he was an Associate Professor in the Department of Computer Science, University Autónoma de Barcelona, Spain. Since 1989 he has been a Full Professor in the University of La Laguna, Tenerife, Spain. His areas of interest include computer architecture and computer education.

Carina Soledad González González received her Ph.D. (Cum Laude) in computer science from the University of La Laguna (ULL), Spain, in 2001. Currently she teaches in the Department of Systems Engineering and Control and Computer Architecture of ULL. She has a Ph.D. in Computer Science, specialising in AI and HCI techniques, her Ph.D. was on the developing of an Intelligent Tutoring System (ITS) to support children with SEN. Her main focus area in research is the application of AI techniques, multimedia adaptive interfaces and social video games in Education. Also, she has a wide experience of e-learning best practices and LMS systems.

Evelio Gonzalez received his MS degree in Applied Physics in 1998 and his Ph.D. degree in Computer Science in 2004 from the University of La Laguna, Tenerife, Spain. From 1998 to 2001 he was a Research Student in the Department of Applied Physics, Electronics and Systems at the same university. Currently, he works as Assistant Professor in the University de La Laguna. His areas of interest include simulation, digital control, computer architecture, artificial intelligence and intelligent agents.

B. Popescu was born in Targoviste, Romania. She received her degree in Computer Science in 2004 from the University of Bucharest, Romania. Between 2004 to 2005 she worked as a programmer at GZK Software, Bucharest, Romania. Since 2006 she has a held a scholarship at the University of La Laguna, Spain.

Claudia Lisete Oliveira Groenwald received her MS degree in Mathematics from the Universidade do Vale do Rio dos Sinos, Brazil, in 1984, and her Ph.D. degree from the Universidad Pontifícia de Salamanca, Spain, in 1997. She is currently an Associate Professor in the Universidade Luterana do Brasil. Her areas of interest include Mathematics Education and Information and Communication Technologies in Education. From 2003 to 2009 she was director of SBEM/RS and she is currently secretary of CIAEM.