Supporting Learning in Introductory Computer Science Courses through the SCALE Environment

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Abstract. The work presented in this paper aims to support and promote the learning process in introductory computer science courses by engaging students actively in various learning activities. The activities are designed following contemporary theories of learning and assessment and are available through the web-based adaptive collaborative learning environment SCALE. The paper discusses the main features of the SCALE environment and the design of learning activities, gives an outline of indicative activities developed and presents preliminary results of a pilot study conducted in the context of an introductory computer science course.

Introduction

The main goal of introductory computer science courses included in the undergraduate curriculum of Computer Science departments is to establish basic foundations for further study (ACM/IEEE-Curriculum 2005 Task Force, 2005), to stimulate students’ interest and to provide cognitive “hooks” which allow tying new material to things already known (Braught, 2001). A vital issue of an undergraduate curriculum in computer science is how to expose the first year students in the computer science. Throughout the history of Computer Science education, the structure of the introductory computer science course has been the subject of intense debate. The wide range of students’ background from complete novices to students with many years of self-taught experience makes the management of the course a difficult task (Kay, 1998). Also, another issue refers to the content of the course, which should remain pact with tendencies, concepts, programming languages, hardware and software of this rapidly extending and developing science. Due to the large number of students and the limited number of hours, the teaching method that is mostly used is based on lectures and assignments. However, this method favours memorization of basic concepts and makes students to loose their interest and have progressively limited attendance to the lecture.

The World Wide Web offers an innovative instructional delivery system that enables the combination of various media for the provision of educational material and the rapid update of the material, connects learners with alternative educational resources and offers the possibility for synchronous and/or asynchronous communication and collaboration. Current research efforts result in environments that are student-centred, engage students in activities, encourage students to take control over their own learning and collaborate with other students and give emphasis on understanding, critical thinking and metacognitive skills. Moreover, current web-based learning environments aim to promote the development of educational material that: (i) is based on contemporary learning theories and blended learning techniques, (ii) results from the cooperation of teachers, learners, educational researchers and graphic experts, (iii) addresses the needs of different learning styles, and (iv) is easily editable, extendable and reusable (Hadjerrouit, 2005). Through the last decade many web-based educational systems, developed in research level, managed to serve successfully individualized learning, collaborative learning and assessment (Weber & Brusilovski, 2001; Stahl et al. 2006). Furthermore, learning management systems such as Blackboard, WebCT and TopClass, successfully promote e-learning and support the learning process and the exchange of educational material between online students.

Towards the direction of covering the limitations and facing the problems imposed by the traditional teaching method, fulfil the instructional needs of introductory computer science courses and extend the capabilities of the abovementioned web-based educational systems, the Department of Informatics and Telecommunications of the University of Athens proposes the exploitation of a web-based educational environment referred to as SCALE (Supporting Collaboration and Adaptation in a Learning Environment) to support the teaching and learning processes in the context of introductory computer science courses. The main objective of SCALE is to engage students actively in the learning process through the elaboration of activities, which aim to cover the diverse needs of the students. SCALE has been developed taking into consideration contemporary tendencies in learning and assessment, which emphasize the active participation of students in learning environments that (i) exploit their pre-existing knowledge, (ii) encourage their collaboration, (iii)
interweave learning and assessment, (iv) develop skills such as critical thinking, teamwork, decision-making, self-monitoring and regulation, and (v) accommodate students’ individual characteristics.

The rest of the paper is structured as follows. In the next section a presentation of the capabilities of the SCALE environment is resumed. Following, the topics supported and the indicative activities developed in the context of an introductory Computer Science course are presented. Finally, a pilot application of the SCALE environment is delineated. The paper concludes with our near future plans.

Outline of the SCALE Environment

The SCALE environment (available at http://hermes.di.uoa.gr:8080/scale) (Gogoulou et al. 2007) is a web-based, adaptive, activity-oriented learning environment that aims to support students not only in the learning process but also in the assessment process. SCALE can be used in any subject matter and provides functionalities that enable students to: (i) work out individual and collaborative activities which are proposed by the environment with respect to students’ knowledge level, (ii) have access to feedback tailored to their own preferences, (iii) have control on the navigation route through the provided activities and feedback components, (iv) participate actively in the assessment process in the context of self-, peer- and/or collaborative-assessment activities by activating the PECASSE environment (Gouli et al. 2006), (v) work with educational environments that facilitate the elaboration of the activities and stimulate students’ active involvement, (vi) use the asynchronous communication tool embedded in SCALE or the ACT tool (Gogoulou et al. 2005) that supports synchronous collaboration/communication.

An activity in SCALE serves a specific learning goal, which corresponds to fundamental concept(s) of the subject matter. The learning goal is further analysed to learning outcomes of comprehension, application, etc level. An activity may consist of one or more sub-activities that address and realize the outcomes of the activity. Also, a sub-activity may consist of one or more question items. The sub-activities may be individual serving the individualized dimension of learning or collaborative serving the collaborative dimension of learning. The activities/sub-activities may have different difficulty level and different degree of importance for the accomplishment of the underlying goal with respect to the educational function (e.g. elicitation/assessment of student’s prior knowledge concerning specific concepts, construction of new knowledge) and the addressed learning outcomes.

The activities are discriminated to the following categories: (i) Prerequisite activities that aim at the ascertainment of student’s prior knowledge concerning the prerequisite concepts and at his/her familiarization with these concepts, (ii) Learning activities that support the knowledge construction process and the development of skills such as critical thinking, revision, reflection and self-regulation, and (iii) Evaluation activities that aim to assess the degree of achieving the expected learning outcomes and the student’s overall knowledge construction as well as to enable the refinement of student’s knowledge in the context of the concept under consideration. The evaluation activities are individual and may serve either summative assessment of the underlying concept or placement assessment for those concepts which have the specific concept as prerequisite.

Depending on the educational function that the activity serves and the underlying outcomes, the assessment may be done either automatically by the system or by peers through the PECASSE environment (in case self-, peer- and/or collaborative-assessment methods are applied) or by the teacher through the SCALE authoring environment. The SCALE authoring environment offers various facilities that allow the teacher to develop activities and feedback material, manage the students enrolled to a specific subject matter and monitor student model (i.e. performance, interaction behaviour, personal characteristics) and progress.

During the elaboration of the activities in SCALE, multiple informative and tutoring feedback components may be provided. The informative feedback components (i.e. correctness-incorrectness of response and performance feedback) inform students about their current state; this information is included in the student model, which is maintained by the environment during the interaction. The tutoring feedback components aim to tutor/guide students and are structured in two levels, activity level and sub-activity level. The feedback components of the sub-activity level refer to the concepts of the sub-activity under consideration, while at activity level, feedback components are more general and address concepts/topics of the activity. The tutoring feedback components are associated with various types of knowledge modules (feedback types), structured in two levels, explanatory level and exploratory level. The explanatory level may include knowledge modules such as a description or a definition of the concept/topic, and the correct response whilst the exploratory level may include (i) an image, (ii) an example, (iii) an advice or an instruction on how to proceed, (iv) a question giving students a hint on what to think about, (v) a case study, (vi) a similar activity followed by its answer, and (vii) any answers given to the specific activity by other students. The different levels and types of knowledge modules aim to serve students’ individual preferences and to cultivate skills such as critical and analytical thinking, ability to compare and combine alternative solutions, etc. In any case, the teacher is responsible to design and develop the appropriate knowledge modules of each level through the SCALE authoring environment, taking into
account several factors such as the content of the activity/sub-activity under consideration, the difficulty level of the specific activity and the addressed learning outcomes.

In SCALE, a navigation route through the provided activities and feedback components is proposed, based on student’s knowledge level and preferences respectively. Students’ navigation is supported by using a graphical icon to point out the recommended activities and feedback components, aiming to support students in achieving the underlying learning goals following their own progress. The student has the possibility to ignore the system’s recommendations and follow his/her navigation route. More specifically, the technology of adaptive link annotation is used in order to generate a sequence of activities and feedback components that gradually guide students to accomplish specific activity-related learning outcomes, and finally meet the selected learning goal. SCALE plans the delivery of the activities for a particular student (in the context of a learning goal), based on his/her progress with respect to the educational function served by the activity and its difficulty level. For the delivery of the supported tutoring feedback components, SCALE takes into account student’s preferences and the delivery sequence proposed by the teacher. As it is considered essential to allow students to play an active role and take control over their own learning in order to meet their needs and preferences, SCALE gives students the possibility to have control over the activities and feedback components presented by selecting the preferred activity to work out as well as the desired feedback component.

The User Interface

Figures 1 and 2 present the main screens of the SCALE environment after student’s selection of an activity or a sub-activity respectively. From each screen the student has the possibility to: (i) access his/her model through the option Learner Model, (ii) view/study the available tutoring feedback components at activity level through the option Personal Assistant, (iii) choose the educational tools necessary for the elaboration of the activity through the option Educational Tool, (iv) access the notebook of the activity through the option Notebook, on which student can maintain personal notes and access notes published from their co-students for the specific activity, and (v) access the activity’s indicators through the option Activity Indicators.

**Figure 1**: Screenshot of the activity “Sequential Search”. The four sub-activities address learning outcomes of the Comprehension level while the fifth sub-activity addresses learning outcomes of the Application level.

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Figure 1 is the main screen of the learning activity “Sequential Search”, which is one of the learning activities developed for the concept of “Algorithms” in the context of the subject matter “Introduction to Informatics and Telecommunications”. This activity includes five sub-activities. The “Sub-activity 1” addresses learning outcomes of the Comprehension level (i.e. Expected Learning Outcomes), has a difficulty level two with maximum five, is individual (i.e. Subactivity Type), is automatically assessed by the system (i.e. Assessment Form), has been already submitted by the specific student (i.e. Status) and has available tutoring feedback components at sub-activity level (i.e. Feedback).
In Figure 2, the two question items of the “Subactivity4” of the activity “Sequential Search” are presented. The type of both question items is multiple choice with one correct answer. From this screen the student can submit his/her answer and get informed about the correctness of his/her answer.

![Figure 2: Screenshot of the Subactivity4 concerning the complexity of the sequential search algorithm.]

**Developing Activities for Computer Science Courses in SCALE**

Having as an objective to support the learning process in the context of the subject matter “Introduction in Informatics and Telecommunications” at the Informatics and Telecommunications Department of the University of Athens, we developed educational material in the form of activities that exploit the facilities of the SCALE environment. The activities can be used (i) by the teacher as laboratory based exercises or as homework, and (ii) by students to delight in the underlying topics or to prepare themselves for the corresponding university or college courses. The developed activities cover the following topics: (i) Data Storage, (ii) Data Manipulation, (iii) Operating Systems, (iv) Networking and Internet, (v) Algorithms, (vi) Programming Languages, (vii) Database Systems, (viii) Data Abstractions, and (ix) Artificial Intelligent. Each topic has been approached at introductory level, aiming to support high school and first year students of computer science departments.

Each activity consists of one or more sub-activities; and each sub-activity of one or more question items. The activity/sub-activity addresses learning outcomes of the Comprehension and/or the Application level. The question items are (i) multiple choice questions with one correct answer, (ii) multiple choice questions with more than one correct answers, (iii) matching questions, (iv) two-tier questions, where the second tier explores students’ reasons for the choice made in the first tier (Tsai & Chou, 2002), and (iv) short answer questions. Although SCALE supports the elaboration of collaborative activities, during the pilot phase of using the environment only individual activities are supported. The activities are automatically assessed by the system and aim to support the learning process of students with diverse backgrounds. This goal is attained through the provision of activities with diverse difficulty level and supported with multiple and different kind of feedback modules. The system proposes activities based on student’s competence level, engaging students gradually to the elaboration of activities with increasingly difficulty level. In the following, indicative activities developed for the topic “Algorithm” are described. The activities can be used in the context of teaching/learning introductory programming and algorithm concepts in secondary or tertiary education.

**Indicative Activities**

*Prerequisite Activity:* The activity “Problems: Definitions - Classifications” aims not only to assess the student’s prior knowledge level, but also to support the knowledge construction process concerning the formulation, analysis and classification of problems. After the elaboration of the specific activity, students will be able to (i) define a problem, (ii) identify the assumptions and the requirements of a problem, (iii) specify errors in the formulation of a problem, (iv) mention the classifications of problems, and (iv) classify problems depending on their solution’s capability, structuring degree and solution classification. This activity consists of
The activity “Sequential search” aims to the comprehension of the characteristics and the function of the sequential search algorithm. After the elaboration of the activity, students will be able to (i) describe thoroughly every step of the sequential search algorithm, (ii) compute the worst case arity of comparisons, executed in order to find a specific element in an one-dimensional array, and (iii) locate the differences at the application of the sequential search algorithm in sorted and unsorted one-dimensional array. This activity consists of five sub-activities (Figures 1 and 2) which attempt to engage student gradually to the characteristics, the operation, and the complexity of the sequential search algorithm. Although the individualized elaboration of the activity in the computer laboratory is recommended, the students can also work collaboratively.

**Evaluation Activity:** The activity “Basic Differences between Sequential and Binary search algorithms” aims to identify whether students are able to (i) recognize problems that can be solved by using either the sequential or the binary search algorithm, and (ii) identify the differences of the two algorithms in terms of their functional characteristics and complexity. The activity consists of four sub-activities consisting of multiple choice and short answer questions that enable students to elaborate on the characteristics of the two algorithms and to make inferences for their advantages and disadvantages in solving specific problems.

**A Pilot Study**

Having as an objective to explore whether the educational material (activities and feedback components) provided through SCALE and the supported facilities of the environment may support the first year students during their exploration of diverse topics of Computer Science, we conducted a pilot study. Particularly, the main research questions were:

1. Which are the ways that students work with SCALE and what is their opinion about the educational material and the provided facilities?
2. Can SCALE and the embedded educational material support and stimulate the learning process during an Introductory Computer Science course?
3. What is the teachers’ opinion about the effectiveness of SCALE in supporting the learning process in the context of an Introductory Computer Science course?

The pilot study is currently in progress in the context of the course “Introduction to Informatics and Telecommunications” at the Department of Informatics and Telecommunications of the National and Kapodistrian University of Athens. The course is compulsory and is taught 3 hours per week. Three teachers are responsible for the management of the course. The students’ and the teachers’ opinion about the effectiveness of SCALE and the developed material is going to be systematically investigated through questionnaires after the run of the course.

The 197 students that enrolled to the course participated in a pre-test aiming to assess their prior knowledge about the topics covered. 88 out of 197 students volunteered to participate in the study and formed the experimental group. These students are to be rewarded with 20% bonus at the course’s final score. The rest 109 students formed the control group and attended to the course without exploiting SCALE environment. The students of the experimental group had to work out a series of individual activities aiming to their better preparation for the final exams of the course and to deepen their thoughts to the covered topics. It was strongly suggested to access the environment and work out the corresponding activities at a week’s basis following the lecture’s material. The estimated weekly time that students worked with SCALE is 2 hours.

Although the study is still in progress, the preliminary results concerning the way students worked with the material devoted to the topic “Data Storage” and specifically to the concept of “Main Memory” indicate that (i) approximately half of the students (59%) worked out the corresponding activity successfully without consulting any kind of tutoring feedback; 12% of these students tried more than one times to answer the questions of the activity after receiving feedback concerning the incorrectness of their answer, (ii) the rest of the students (41%) worked out the corresponding activity successfully, after receiving tutoring feedback components; more specifically, 35% of the students answered correctly the questions of the activity after receiving as feedback the “correct answer”, (iii) the average rate of the activity’s elaboration attempts was 2.
Based on conversations made with students during classes, the positive influence of the SCALE environment and the educational material to a more constructive and effective learning can be stated. The students of the experimental group are more active and tend to ask more questions during the lecture in order to relate the presented theory and their prior knowledge with the educational material provided through SCALE.

Summary and Future Plans

The learning process in introductory computer science courses can be supported and enhanced through web-based educational material that follows contemporary tendencies in learning and assessment. In this context, the SCALE environment offers various functionalities such as elaboration of individual and collaborative activities, multiple informative and tutoring feedback components both at the activity and the sub-activity level, tools for synchronous and asynchronous communication and various forms of assessment. The activities that we developed and are available through SCALE cover a range of topics and can be used in the context of introductory computer science courses in secondary or tertiary education. Although, the preliminary results of the pilot application of this material in real classroom settings are encouraging and positive, the systematic analysis of the whole process is required in order to draw inferences for the effectiveness of the proposed material and the students’ and teachers’ opinion. Also, we plan to develop and supplement the material with collaborative activities, aiming to promote the cultivation of collaborative learning skills.

References


