COFALE: An Authoring System for Creating Web-based Adaptive Learning Environments Supporting Cognitive Flexibility

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***Abstract*—Constructivism is a learning theory that states that people learn by actively constructing their own knowledge, based on prior knowledge. A significant number of ICT-based constructivist learning systems have been proposed in recent years. A critical problem related to the design and use of this kind of systems has been the lack of a practical means to facilitate the instructional design process. Our research aims to help designing truly constructivist and adaptive learning environments. Our approach is based on a set of operational criteria for certain aspects of constructivism: We use these criteria as a useful pedagogical framework to provide tools and guidelines facilitating the instructional design process.**

One facet often mentioned as being strongly relevant to constructivism is cognitive flexibility. This paper presents COFALE—a new, domain-independent, and open-source e-learning platform that could be used to build adaptive learning environments supporting cognitive flexibility—and an example of its use: the design of a course on recursion.

***Index Terms*—E-learning, constructivism, adaptability, open-source platforms, operational criteria, operational approaches**

I. Introduction, Background, and Context

A. Constructivism, Adaptability, and Instructinal Design

Piagetian or cognitive constructivism [25] is an educational approach that "emphasizes that individuals learn best when they actively construct knowledge and understanding" (Santrock [26], p. 318). Constructivist learning is a process of active construction and transformation of knowledge [4]. Bruner [5] introduces the following example of constructivist learning:

> The concept of prime numbers appears to be more readily grasped when the child, through construction, discovers that certain handfuls of beans cannot be laid out in completed rows and columns. Such quantities have either to be laid out in a single file or in an incomplete row-column design in which there is always one extra or one too few to fill the pattern. These patterns, the child learns, happen to be called prime. It is easy for the child to go from this step to the recognition that a multiple table, so called, is a record sheet of quantities in completed multiple rows and columns. Here is factoring, multiplication and primes in a construction that can be visualized.

A counter-example of constructivist learning would be a case in which the child is given a textual definition to learn the concept of prime numbers. This situation may not foster learning, from a constructivist point of view, because it could lead to "rote" or passive learning [10].

In recent years, constructivist beliefs and practices have been widely adopted, as evidenced by the appearance of a significant number of ICT-based constructivist learning systems [21] (ICT stands for information and communication technology). Many researchers accept the central assumption of constructivism as stated by Santrock; however, they derive different pedagogical implications from the same basic principles. Driscoll [17], for instance, identifies five major facets of constructivism related to instructional design: (1) reasoning, critical thinking, and problem solving; (2) retention, understanding, and use; (3) cognitive flexibility; (4) self-regulation; and (5) mindful reflection and epistemic flexibility.

A major problem related to the design and use of constructivist learning systems has been that, while many pedagogical principles for constructivism exist, there is little *practical* advice on how to exploit advanced learning technologies to exhibit constructivist principles.

Another important characteristic we would like to see in ICT-based learning systems is scaffolding or adaptability, meaning the ability of a learning system to provide a learning experience that is continuously tailored to the needs of the individual learner [6, 24]. Adaptation support is important because most students within an ICT-based learning environment have different personal characteristics such as prior knowledge, learning progress [24].

B. Constributions

In earlier work [8, 10], we have defined a set of operational criteria for cognitive flexibility (**CF**), one of the important facets of constructivism. In [12], we have presented a new authoring system, named COFALE, in which we provide the course designer with tools and **operational** guidelines for creating ICT-based learning environments fostering CF. As an extended paper of [12], in this article we show how to use COFALE to build learning environments supporting both CF and adaptability. We illustrate an example of use of COFALE by devising and evaluating a “course” on recursion.

C. Context for the Example

The concept of recursion is very important in computing science [3]. Many consider that both teaching and learning recursion are difficult because of three main reasons [1, 3]: (1) the concept is unfamiliar (students are induced to proceed by analogy from examples); (2) the concept is complex (it is hard for students to transfer from a pattern of recursion to a new one); and (3) interference may arise from knowledge of other methods of solution (e.g., iterations).

D. Structure of the Paper

Sections II and III introduce necessary background on CF and adaptability; section IV shows how a course designer might use COFALE to build adaptive learning environments leading to CF; section V reports on a preliminary evaluation of COFALE; sections VI and VII present our discussion and conclusion.

II. Cognitive Flexibility

According to Spiro and associates [28, p. 165], CF is “the ability to spontaneously restructure one’s knowledge, in many ways, in adaptive response to radically changing situational demands”. Here are several examples of CF:

- When students are faced with a new problem, they try to analyze different aspects of the problem in a systematic manner and to use different ways they have successfully used in the past to solve similar or related problems in order to find a solution, which is as complete as possible.
- When students are confronted with a new concept, they try to perform different activities in different contexts to look further into various aspects of the new concept.
- When students discuss with peers, they try to listen and ask, in a systematic manner, questions such as “why?” and “what is your source of information?” in an effort to understand other points of view.

The assumptions of Spiro and his colleagues focus on the nature of learning in complex and ill-structured domains; that is, the domains in which cases or examples are diverse, irregular, and complex. They recommend that teachers encourage learners to treat multiple aspects of and multiple perspectives on problems in real situations. They advocate the use of multiple forms of pedagogical models, multiple metaphors and analogies, and multiple interpretations of the same information [18].

Another point of view proposed by Bourgeois and Nizet [4] about CF stresses that teachers should encourage learners to explore new knowledge further possible in various concrete situations. On the other hand, they add, it is necessary to give means allowing learners to analyze and evaluate this new knowledge “from the outside”. According to this approach, teachers are responsible for three activities: (1) engage learners in expressing their personal points of view; (2) organize the confrontation of learners’ points of view; and (3) provide methodological tools allowing learners to treat these different points of view.

Driscoll [17] examines the assumptions proposed by Spiro and his associates and identifies two principal learning conditions that stimulate CF: (1) multiple modes of learning (i.e., multiple representations of contents, multiple ways and methods for exploring contents); and (2) multiple perspectives on learning (i.e., expression, confrontation, and treatment of multiple points of view).

In earlier work [8, 10], we transformed the pedagogical principles underlying the previous two learning conditions for CF into operational criteria and we showed examples of their use. We defined an operational criterion for CF to be a test that allows a straightforward decision about whether or not a learning situation reflects the pedagogical principles underlying CF. We first examined many existing learning systems and identified four main components of learning systems: (1) learning contents (e.g., concept definitions); (2) pedagogical devices (e.g., tools provided for learners for exploring learning contents); (3) human interactions (e.g., means for engaging tutors and learners in exchanges); and (4) assessment (e.g., post-tests for determining whether learners have achieved learning objectives). Then, in each of the four learning components and for each of the two learning conditions for CF, we proposed criteria that can be applied for checking the presence of the learning condition in the learning component, as follows (MM = multiple modes, MP = multiple perspectives):

Criteria for learning contents

MM1: *The same learning content presenting concepts and their relationships is represented in different forms (e.g., text, images, audio, video, simulations).*

MP1: *The same abstract concept is explained, used, and applied systematically with other concepts in a diversity of examples of use, exercises, and case studies in complex, realistic, and relevant situations.*

Criteria for pedagogical devices

MM2: *Learners are encouraged to study the same abstract concept for different purposes, at different times, by different methods including different activities (reading, exploring, knowledge reorganization, etc.).*

MP2: *When facing a new concept, learners are encouraged to explore the relationships between this concept and other ones as far as possible in complex, realistic, and relevant situations.*

MP3: *When facing a new concept, learners are encouraged to explore different interpretations of this concept (by other authors and by peers), to express their personal point of view on the new concept, and to give feedback on the points of view of other people.*

MP4: *When facing a new concept, learners are encouraged to examine, analyze, and synthesize a diversity of points of view on the new concept.*

Criteria for human interactions

MM3: *The number of participants, the type of participant (learner, tutor, expert, etc.), the communication tools (e-mail, mailing lists, face to face, chat room, video conferencing, etc.), and the location (in the classroom, on campus, anywhere in the world, etc.) are varied.*

MP5: *During the discussion, learners are encouraged to diversify – as far as possible – the different points of view about the topic discussed.*

Criteria for assessment

MM4: *During the learning process, learners are encouraged to use different assessment methods and tools, at different times, and in different contexts for demonstrating their ability to solve different problems.*

MP6: *During the problem-solving process, learners are encouraged to confront multiple ways to solve the problem and multiple possible solutions to the problem.*

In section IV, we show how the course designer might use authoring tools provided by the COFALE system to satisfy criteria for CF.

III. Mental Models And Adaptability

A. Mental Models

In a constructivist point of view, each learner possesses a mental model (i.e., a mental representation or knowledge structure) about a concept or a situation at any point in time. The purpose of learning is to have the mental model get closer and closer to that subsumed by the learning objectives. Through personal experience, the learner may undergo a certain number of cognitive changes and then develop a higher mental model. For instance, a beginner could start with a "novice" model on a given subject and gradually evolve toward an “expert” model through his or her own learning. One of the major roles of the designer of a "course" is thus to provide the learner with appropriate learning conditions to facilitate the learner’s process of knowledge construction and transformation [4].

Several researchers [1, 3] interviewed many students and analyzed students’ tests on the subject of recursion. They distinguished four approaches that students try to apply to generate recursive solutions to a given problem:

- *Loop model*: “Novice” students, when constructing a recursive solution, try to adapt some part of an iterative structure, for example the updating of loop index variables, to achieve recursion. That is why they often produce incorrect recursive solutions to a given problem.
- *Syntactic model*: Students consider recursion as a template consisting of a base case and a recursive part. Although they may not fully understand the functionality of the recursive part, they are able to solve simple problems by filling the condition part and the action part of the base case and the recursive part.
- *Analytic model*: Students consider recursion as a problem-solving technique. They analyze diverse cases of a given problem; then, for each case, they determine input conditions and output actions; finally, they write recursive code.
- *Analysis-synthesis model*: “Expert” students, in addition to the ability implied by the analytic model, are able to apply the DCG (Divide, Conquer, and Glue) strategy to solve problems recursively: They break a large problem into one or more sub-problems that are identical in structure to the original problem and somewhat simpler to solve.

From our point of view, each of the previous methods may be seen as defining the mental model of a learner getting acquainted with the concept and applications of recursion.

B. Adaptability

A particular type of adaptation support that is often mentioned by constructivist theorists is scaffolding, meaning that the teacher should change the level of support over the course of a learning session of a particular learner [26]. In other words, a more skilled person (teacher or more-advanced peer) adjusts the amount of guidance to adapt the learner’s current performance level or mental model. For instance, when the learner confronts a new situation, the tutor might guide and encourage the learner in the learning process; as the learner’s competence increases, the support is adjusted or removed [27].

Brusilovsky and Peylo [7] have presented five main techniques for implementing adaptability: (1) presentation of learning contents (e.g., define which contents are appropriate to a specific learner at any given time); (2) presentation of pedagogical devices (e.g., define which learning activities are appropriate to a specific learner); (3) communication support (e.g., identify which peers are appropriate to help a specific learner); (4) assessment (e.g., identify which assessment problems and methods are appropriate to determine the actual performance of a specific learner); and (5) problem-solving support (e.g., give appropriate feedback during the problem-solving process of a specific learner).

The next section shows how the course designer might use COFALE’s authoring tools to adapt the learning contents, pedagogical devices, and communication support to different kinds of learners, in a manner consistent with the constructivist point of view presented earlier (i.e., scaffolding).

IV. COFALE As An Authoring System

COFALE is an open-source, Web-based, adaptive e-learning platform that supports CF explicitly. COFALE is based on ATutor [2], a learning content management system (LCMS). In the following sub-sections, we show how a course designer (Tom) might use authoring tools provided by COFALE to create an adaptive learning environment fostering CF for the concept of recursion.

Notice that a number of authoring tools are originally supported by ATutor (thus also by COFALE).

A. *Tools for Supporting Cognitive Flexibility*

For the purpose of the discussion, we shall assume that a "novice" learner (Bob), familiar with "traditional" programming (say in the Java language), wants to learn recursion (i.e., to develop the ability to solve problems recursively). In this sub-section, we show for each criterion for CF presented in section II, how Tom uses Web-based authoring tools to present Bob with learning situations satisfying the corresponding criterion.

Criteria MM1 and MP1: To help Bob understand how to apply the concept of recursion in different contexts (criterion MP1), Tom provides Bob with several learning situations. For instance, arithmetic expressions (Figure 1) explain the use of recursion in binary trees in a natural way, and simple text search explains how to apply recursion to represent a text (i.e., a list of words) as a linked list and to look up a phrase in a document. Note that criterion MP1 is independent to ICT and that Tom must be versed in the subject of recursion to be able to prepare a *diversity* of learning situations for the student.

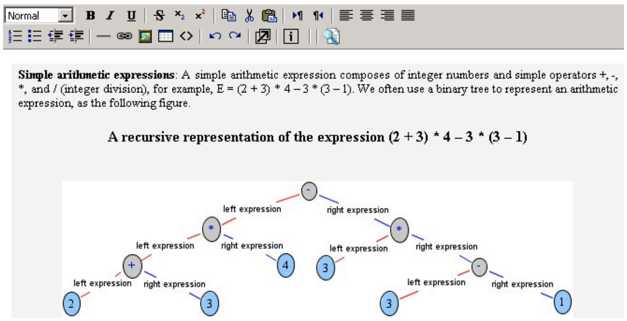


Figure 1. Tool for creating content objects

To satisfy criterion MM1, Tom has made multiple representations available for recursion: a combination of text, images, and simulations helps Bob grasp diverse aspects of recursion better than a single text does. For example, ATutor provides Tom with a hypermedia tool (Figure 1) to create learning content objects (content pages) in different forms.

Criterion MM2: To encourage Bob to look further into the concept of recursion, Tom presents Bob with a number of learning activities at the end of each content page, for example, at the end of the final page of the situation about arithmetic expressions, Bob is invited to explore related topics, to add comments, to do tests, to discuss with peers, and so on.

COFALE supports a set of predefined learning activities (Figure 2), most of which are associated with a hyperlink, which allows learners to go directly to the pedagogical device(s) corresponding to the activity. To define, for each activity (e.g., "Examples & Summaries"), the content pages to which the activity is related, Tom first clicks on the command "Edit" next to the activity (Figure 2), then Tom selects the checkboxes next to the content pages he wants to associate with the learning activity (Figure 3). On the basis of those associations, at the end of each selected page, COFALE presents Bob with a hyperlink to the activity (i.e., "Examples & Summaries").

Learning Activities

Name	Description	Edit
Personal Comments	Add personal comments on the current content page.	· Edit
Next Page	Explore the next content page using the local menu on the right or the link at the bottom.	· Edit
Related Topics	Explore related concepts or situations using the menu "Related Topics" on the right.	· Edit
Learning History	Return to recently visited content pages using the menu "Learning History" on the right.	· Edit
Examples & Summaries	Add examples, concept maps, and summaries related to the current learning objective.	· Edit
Other Resources	Explore other resources related to the current learning objective.	· Edit
Peers' Learning Hyperspace	Explore peers' learning space to see how they learn the current learning objective.	· Edit
Tests	Do tests related to the current learning objective.	· Edit
Dicussions	Discuss with peers about the current learning objective.	· Edit
Collaboration	Work in group to find out solutions for complex problems related to the current learning objective.	· Edit

Figure 2. Predefined learning activities in COFALE

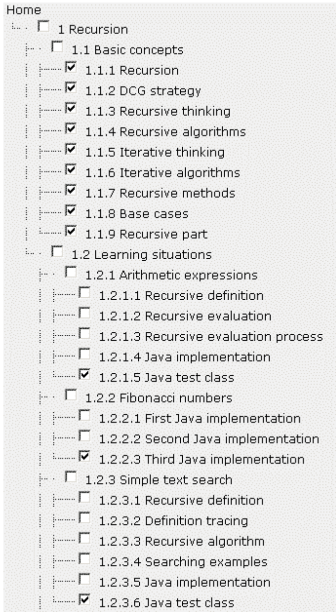


Figure 3. Tool for defining pages related to an activity

Criterion MP2: To encourage Bob to explore related topics (e.g., simple text search) while he is examining a learning situation (e.g., arithmetic expressions), Tom needs to define relationships among content objects. For instance, the tool (Figure 4) provided by ATutor allows Tom to associate "Simple text search" with "Arithmetic expressions" by selecting the checkbox next to "Simple text search". On the basis of those definitions, COFALE automatically generates the hyperlinks in a menu "Related Topics", presented to Bob in his learning hyperspace (see also [9]).

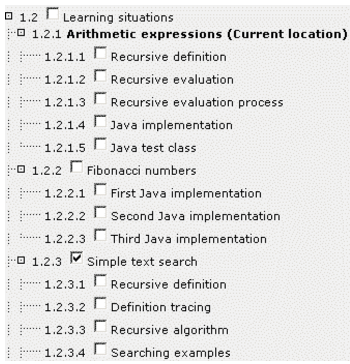


Figure 4. Tool for defining "related topics" relations

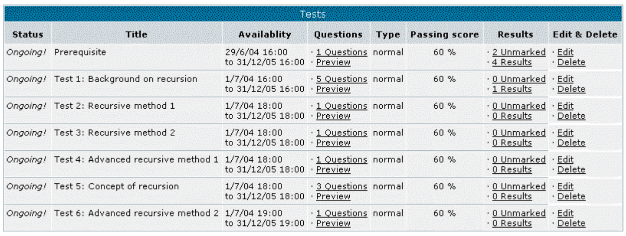
Criterion MP3: COFALE satisfies this criterion without Tom's explicit intervention. For instance, it engages Bob in the following activities: (1) add comments on the learning content proposed by Tom, for example, reformulate the main points of the definition of recursion, (2) add his own examples such as a recursive phenomenon in his life, (3) explore peers' learning spaces, for example, log into the learning hyperspace of an "expert" learner to see her own recursive examples.

Criterion MP4: COFALE also satisfies this criterion without Tom's intervention, for instance, it provides Bob with an empty table so that he can state his own definitions of recursion, recursive methods, and recursive problem solving, together with peers'.

Criterion MM3: To satisfy this criterion, Tom uses a tool provided by ATutor to create forums for learners to exchange, for example, to confront and discuss their recursive examples that they have encountered in their everyday life. Tom also searches the Internet for Q&A websites to encourage learners to ask experts questions about recursion. In addition, Tom often participates in mailing lists, chat rooms supported by ATutor to foster students' learning.

Criterion MP5: To help Bob elicit peers' point of view during discussion, Tom uses tools provided by COFALE to introduce a list of general questions proposed by educational theorists [31] and a list of domain-specific questions. For example: Does anyone have a different opinion? What is the source of your information? Why? Why recursion should be used in this problem? How do you go from the problem specification to your recursive solution? COFALE attaches the two lists of questions to each of students' communication tools.

Criterion MM4: ATutor provides Tom with a test manager (Figure 5) so that he can create individual tests, for example, introduce an assessment situation, a passing score, one or more questions, start and end dates. Presently, Tom can create three types of questions: multiple-choice, true/false, and open-ended.



Tests

Status	Title	Availablity	Questions	Type	Passing score	Results	Edit & Delete
Ongoing!	Prerequisite	29/6/04 16:00 to 31/12/05 16:00	· 1 Questions · Preview	normal	60 %	· 2 Unmarked · 4 Results	· Edit · Delete
Ongoing!	Test 1: Background on recursion	1/7/04 16:00 to 31/12/05 16:00	· 5 Questions · Preview	normal	60 %	· 0 Unmarked · 1 Results	· Edit · Delete
Ongoing!	Test 2: Recursive method 1	1/7/04 18:00 to 31/12/05 18:00	· 1 Questions · Preview	normal	60 %	· 0 Unmarked · 0 Results	· Edit · Delete
Ongoing!	Test 3: Recursive method 2	1/7/04 18:00 to 31/12/05 18:00	· 1 Questions · Preview	normal	60 %	· 0 Unmarked · 0 Results	· Edit · Delete
Ongoing!	Test 4: Advanced recursive method 1	1/7/04 18:00 to 31/12/05 18:00	· 1 Questions · Preview	normal	60 %	· 0 Unmarked · 0 Results	· Edit · Delete
Ongoing!	Test 5: Concept of recursion	1/7/04 18:00 to 31/12/05 18:00	· 3 Questions · Preview	normal	60 %	· 0 Unmarked · 0 Results	· Edit · Delete
Ongoing!	Test 6: Advanced recursive method 2	1/7/04 19:00 to 31/12/05 19:00	· 1 Questions · Preview	normal	60 %	· 0 Unmarked · 0 Results	· Edit · Delete

Figure 5. Tool for managing individual tests

Furthermore, Tom can use tools (Figure 6) to create assessment situations in groups. For instance, he can constitute different groups of learners, and present them with certain problems in the situation about file management (e.g., listing all files and sub-directories of a given directory in a tree-structured file system) and a brief description of the class File in Java, which is useful for students to solve the given problems (Figure 6: Area 1). Bob and his peers are invited to use this collaboration hyperspace to confront, examine, and compare different recursive solutions to the given problems.

Criterion MP6: Tom must be an expert in the subject of recursion to be able to satisfy this ICT-independent criterion. For instance, Tom has proposed the file-listing assessment problem because it may easily evoke different solutions to the given problem (by students): (1) first list the files and sub-directories in the given directory, then in its sub-directories, (2) first list the files and sub-directories in the sub-directories of the given directory, then in the given directory.

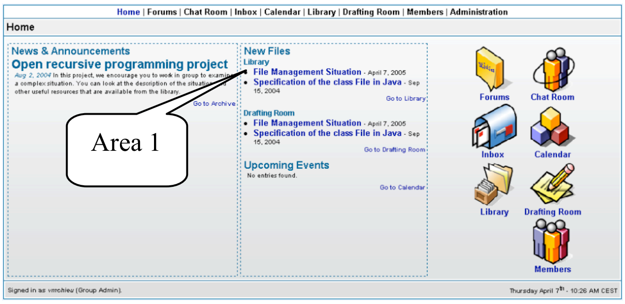
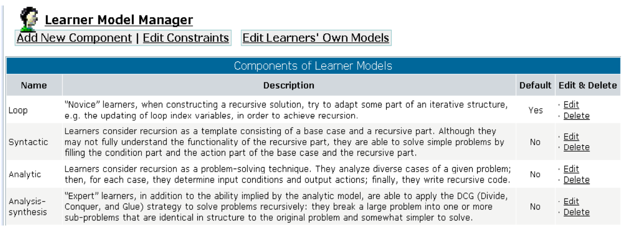


Figure 6. Tools for creating collaboration hyperspace

B. Tools for Adaptation Support

We shall now assume that two other learners (Ted and Alice, both at the "expert" level) are active in the course: They are well versed in the use of COFALE and they have reached the analysis-synthesis model of the recursion concept. In the following paragraphs, we first present the tools provided by COFALE for the course designer (Tom) to define the learner models of recursion described in section III. Then, we show how Tom can use COFALE to support students with adaptive presentation of learning contents, adaptive presentation of pedagogical devices, and adaptive communication support.

Tools for student modeling: COFALE provides Tom with a tool (Figure 7) to create different learner models. For each learner model, Tom needs to specify a name, a description, and an option indicating whether the model is set as default or not. When a model is set as default, COFALE will automatically assign it for every new student of the system. For example, in Figure 7 Tom has defined four models for the concept of recursion: loop, syntactic, analytic, and analysis-synthesis (see section III), and set "loop" as the default model, meaning that when a new student enrolls in the recursion course, he or she will be assumed to possess the loop model of recursion.



Learner Model Manager

Add New Component | Edit Constraints   Edit Learners' Own Models

Components of Learner Models

Name	Description	Default	Edit & Delete
Loop	"Novice" learners, when constructing a recursive solution, try to adapt some part of an iterative structure, e.g. the updating of loop index variables, in order to achieve recursion.	Yes	· Edit · Delete
Syntactic	Learners consider recursion as a template consisting of a base case and a recursive part. Although they may not fully understand the functionality of the recursive part, they are able to solve simple problems by filling the condition part and the action part of the base case and the recursive part.	No	· Edit · Delete
Analytic	Learners consider recursion as a problem-solving technique. They analyze diverse cases of a given problem; then, for each case, they determine input conditions and output actions; finally, they write recursive code.	No	· Edit · Delete
Analysis-synthesis	"Expert" learners, in addition to the ability implied by the analytic model, are able to apply the DCG (Divide, Conquer, and Glue) strategy to solve problems recursively: they break a large problem into one or more sub-problems that are identical in structure to the original problem and somewhat simpler to solve.	No	· Edit · Delete

Figure 7. Tools for managing learner models

During the learning process, three kinds of evaluations of mental models may be performed:

- *Self-evaluation*: For example, after exploring learning situations and doing tests, the student could identify that he or she possesses the analytic model (see Figure 8).
- *Evaluation by the tutor*: For instance, after evaluating the student's tests and learning behavior, Tom could diagnose that the student has reached the syntactic model.
- *Evaluation by COFALE*: On the basis of the student's test results and logic expressions for automatic diagnosis provided by Tom (e.g., in Figure 9, if the student does T1 successfully but not T2, T3, T4, then he or she will be assumed to possess the loop model), COFALE could detect that he or she possesses the loop model.

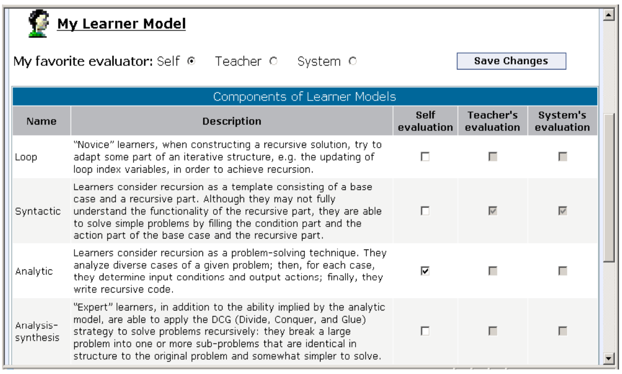


Figure 8. Tool for the student to update his or her learner model

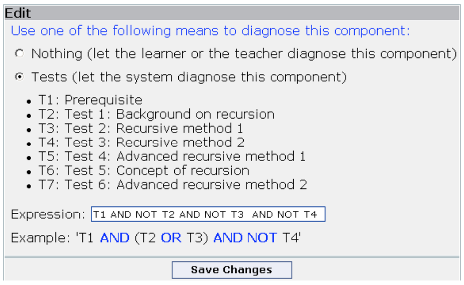


Figure 9. Tool for Tom to define the logic expression for the automatic diagnosis of the loop model

At certain times, for instance after a test, learners may be asked to update the information about their mental model and choose the kind of evaluation they prefer; for instance, the student may decide to always rely on his or her own evaluation (Figure 8). COFALE will immediately adapt the learning contents, pedagogical devices, and communication support to the student's new mental model (see the next paragraphs). A number of researchers [3, 20, 29] have also used the previous techniques to update students' mental models.

Tool for adaptive presentation of learning contents: To support adaptive presentation of learning contents, Tom must first decompose the learning content into fine-grained content objects or pages. For instance, Tom organizes the content of the recursion course into basic concepts and learning situations; basic concepts include recursion, recursive thinking, recursive algorithms; and learning situations include arithmetic expressions, simple text search (Figure 10). Then, Tom selects the appropriate content objects for each kind of students, according to their mental models. For example, in Figure 10 Tom selects the checkboxes next to the content objects he wants to present to the students possessing the loop model of recursion (e.g., Bob). Similarly, Tom uses the same tool to define the suitable content objects for other types of students (e.g., Alice and Ted). This work, of course, is a step in which Tom's understanding of the various mental models among learners is essential. For example, the situation "Fibonacci numbers" is proposed to the students with the loop model of recursion because it may help them master the difference between recursion and iteration, and the situation of "partition" (a partition of a positive integer m is a way to write m as a sum of positive integers; let P_m equal the number of different partitions of m, where the order of terms in the sum does not matter; given m, find P_m) is suggested to the students with the analysis-synthesis model of recursion because it may help them understand how to build recursive solutions to complex problems.

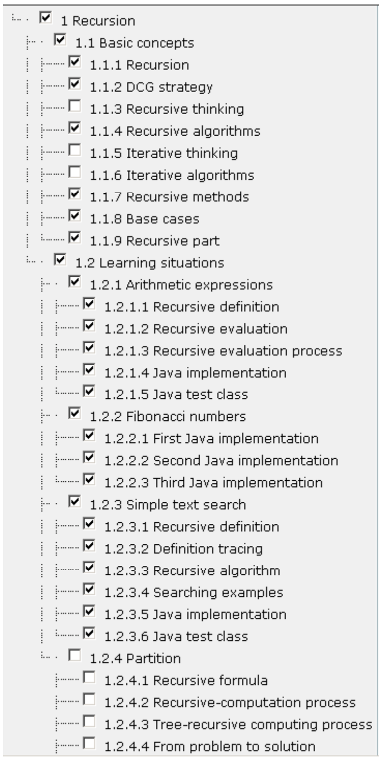


Figure 10. Tool for Tom to define appropriate learning contents for the students possessing the loop model

On the basis of the associations between content objects and mental models, COFALE automatically personalizes the learning content to different kinds of students (Figure 11). When a student (e.g., Bob) makes progress (e.g., develop from a loop model to an analytic model), the set of content objects presented to him will be automatically changed, according to his progress.

Tool for adaptive presentation of pedagogical devices: To guide and encourage the student in the exploration of the learning hyperspace, at the bottom of each content page COFALE presents the student with a number of learning activities (see also the previous sub-section), for instance, 10 activities (Figure 12) presented to Bob (a "novice" student) at the end of the situation about arithmetic expressions. Ted and Alice, however, are at the "expert" level, so COFALE suggests only 5 "advanced" tasks to them (Figure 12). That is a kind of adaptive presentation of pedagogical devices.

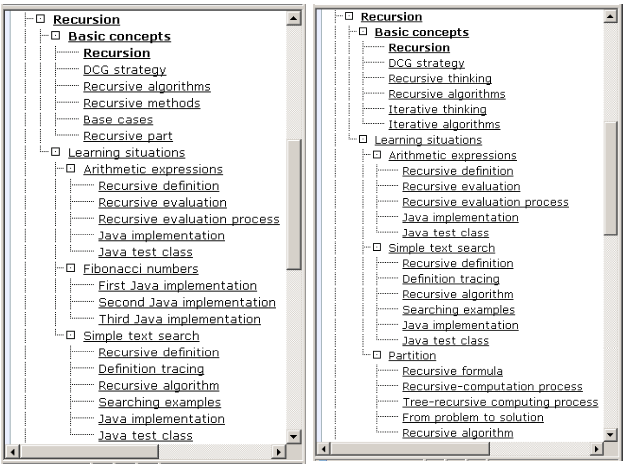


Figure 11. Part of the content proposed to Bob (left) and to Alice (right)

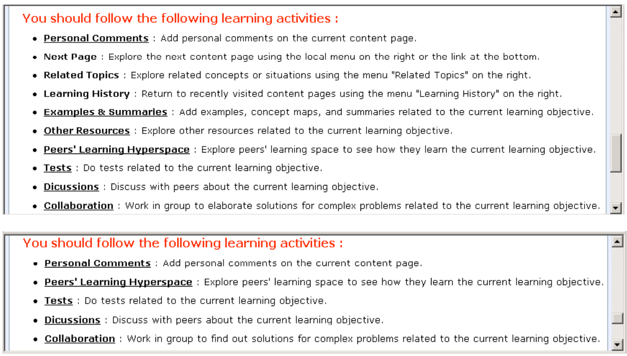


Figure 12. Activities proposed to Bob (above) and to Alice (below)

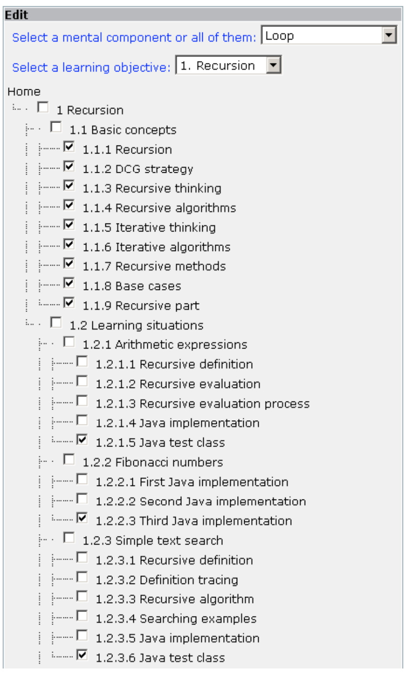


Figure 13. Tool for Tom to define, for the students with the loop model, the contents to which activity "Examples & Summaries" is related

To help Tom implement the previous adaptation support, COFALE provides a set of predefined learning activities (see Figure 2). To define, for each type of learner and for each learning activity, the appropriate content pages to which the activity is related, Tom first clicks on the command "Edit" next to the activity, for instance, "Examples & Summaries" (Figure 2). Then, in Figure 13 Tom selects a mental model (e.g., the loop model), and finally the checkboxes next to the content pages he wants to associate with the selected learning activity (i.e., "Examples & Summaries"). COFALE will present the students possessing the selected model (i.e., "Loop") with the selected learning activity (i.e., "Examples & Summaries") at the bottom of the selected content pages (e.g., "Java test class", the last item of the situation about arithmetic expressions).

Tool for adaptive communication support: While learning with COFALE, students can use a tool to search for peers who could help them overcome their own difficulties. COFALE may, for instance, automatically suggest Ted and Alice to Bob (Figure 14) so that he can ask them questions about simple problems; COFALE may suggest Ted to Alice so that they can exchange ideas about advanced recursive techniques. Moreover, students could use "Advanced Search" (Figure 14) to find particular peers by introducing, for example, their name, gender, mental models. That is a kind of adaptive communication support.

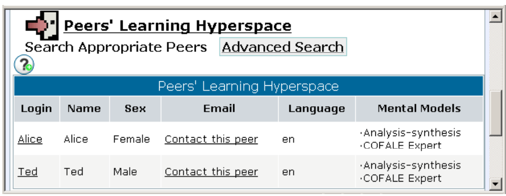


Figure 14. Appropriate peers proposed to Bob

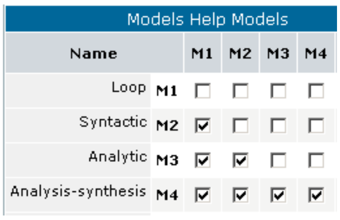


Figure 15. Tool for Tom to defizne appropriate peers for a particular kind of students

To help Tom in implementing the previous adaptation support, COFALE provides a tool (Figure 15) allowing him to define "help" relations among components of learner models: "C_1 R C_2" means that students possessing C_1 can help students possessing C_2 overcome difficulties about acquiring the current learning objective. In Figure 15, to define that M_i helps M_j, Tom selects the checkbox found at the cell (i,j): M_2 helps M_1; M_3 helps M_2 and M_1; M_4 helps M_4, M_3, M_2, and M_1. In general, students with more advanced models could help students with less advanced ones. On the basis of those associations, COFALE automatically finds and suggests a list of appropriate peers to a particular student (Figure 14).

V. PRELIMINARY EVALUATION OF COFALE

A significant number of empirical researches in e-learning, for instance [29], claimed that adaptation support improved students' learning outcomes. A number of studies showed positive results that pedagogical models proposed for CF helped students in advanced knowledge acquisition [28]. The implementation of learning conditions fostering CF in an e-learning platform such as COFALE, however, is relatively new. Thus, it is necessary to carry out a certain number of surveys to evaluate various aspects of the COFALE system. For example: Do learning conditions provided by COFALE foster students' CF effectively? Do students follow suggestions proposed by COFALE (e.g., to explore related concepts and do learning activities presented at the bottom of each page)? More specifically, do their learning processes respect criteria for CF? Nevertheless, the evaluation of learners' cognitive ability must be very hard [15, 30]. For the time being, we could perform only a preliminary study to answer the previous questions partly.

A 2-week-long study was carried out to formatively evaluate the recursion course we designed using COFALE [10]. Here is the method: Nine first-year engineering students at the *Université catholique de Louvain*, with prior knowledge of programming and Java but no knowledge of recursion, were randomly organized into two groups: four in the COFALE group and five in the control group. We organized the study into four phases: pretest, experiment, posttest, and interview. Both groups were given the same pretest, posttest, and interview questions. For the experimental phase, they were given the same 45-minute-long lecture and 2-hour-long homework. The difference was that: After the lecture, within 1 hour the COFALE group explored the recursion course maintained by COFALE whereas the control group read a chapter about recursion of a reference book [22].

Several encouraging results were reported on learning with the help of COFALE. Students in both groups mastered the concept of recursion to a significant degree. The COFALE group's learning behavior, however, seemed to be somewhat more consistent with CF than the control group's. For example: in the posttest, the COFALE group tried to activate their prior knowledge, in different ways, to analyze different aspects of a new problem and to propose a solution as complete as possible than did the control group; in the interview, the COFALE group tried to define the concept of recursion more clearly and accurately than did the control group.

In addition, the following short extract of an interview of a student in the COFALE group could show the effectiveness of criteria MM1 and MP1 in the recursion course we designed in COFALE (the evidence is in italic):

> COFALE is good, personalized… We can work anywhere, submit exercises online … There is not much in one content page… *Many examples, they are clear and well explained, in each example we do not give the solution immediately, there is one page to explain how to think, one page to explain how to build the solution, and one page to show the solution. This helps to construct our own solution by ourselves.*

VI. DISCUSSION

A. Development and Use of COFALE

To understand more about adaptive learning environments supporting CF created by COFALE, one should explore our earlier work [9]. To understand learning tools and authoring tools supported by COFALE completely, one should examine the dissertation of a researcher of ours [10]. To explore the COFALE open-source project (including the online course on recursion), one should visit the following website: "`http://cofale.info.ucl.ac.be`".

COFALE is a domain-independent platform, meaning that it can be used to design "courses" in a variety of domains. Indeed, COFALE is based on ATutor, claimed to be domain-independent [2]. Furthermore, the features COFALE has added on to ATutor are also domain-independent, for example, the tools shown in Figures 2 and 3 could be used in the design of any "courses".

The course designer's workload for making a course available in COFALE is not very high (about 8 person-hours for the course on recursion) because of two main reasons. Firstly, COFALE supports many learning activities without intervention of the course designer. Secondly, operational criteria provide useful guidelines for the course designer.

For the implementation of COFALE, we have modified several components of ATutor and added a number of learning and authoring tools. We have selected ATutor among many open-source LCMSs because it makes it easy to add pedagogical devices exhibiting the desired characteristics for CF and to create and manage fine-grained sharable content objects that are compliant with the IMS/SCORM standard [23]. This latter characteristic is useful both for the design of goal-based learning and for the personalization of learning contents [23]. Our contribution to ATutor is about 20 percent of the source code (or 5,000 lines of PHP code). It is worth to note that the development of the COFALE system has been mainly oriented to the set of criteria for CF and to the set of adaptation techniques: Each learning tool and each authoring tool in COFALE must have at least a *raison d'être*, that is, to be present to satisfy one or more criteria for CF or to implement one or more adaptation techniques. Therefore, the workload for the design and implementation of the COFALE system could be considered as relatively low (about 6 person-months of programming work). That is why we could claim that the operational approach we proposed is effective.

B. Related Work

In earlier work [11], we analyzed several "courses" handled by existing systems, claimed to support constructivism explicitly, with respect to the criteria for CF: a motion course by SimQuest [14], a Moodle features course by Moodle [16], and a Java course by KBS [20]. The analysis (Table I) showed the following main conclusions:

- There would be many different ways to create ICT-based learning conditions fostering CF. For example, we could use computer-based simulations (SimQuest) or hypermedia (Moodle, KBS, and COFALE) to satisfy criteria MM1 and MM2.
- The course designer should take into account the quality of criteria satisfaction rather than only the number of satisfied criteria, meaning that the course designer's expertise in the subject of instruction is essential. For criterion MP1, for instance, one must be an expert in the subject of recursion to be able to devise a diversity of meaningful instructional situations for the concept of recursion (e.g., arithmetic expressions and simple text search). The point here is that preparing a diversity of situations (quality) that emphasize different aspects or interpretations of a new concept is more important than preparing many situations (quantity) that emphasize only one or two aspects of the new concept.
- In practice, it is not necessary to always satisfy all of the criteria for CF: In certain contexts, for example in introductory learning such as SimQuest's motion course, satisfying a half of the criteria might be sufficient enough to help students attain the learning objectives effectively. For the time being, there has been no evidence indicating that satisfying all of the criteria is always better than satisfying, for instance, two thirds of the set of criteria.

TABLE I.
EXISTING LEARNING SYSTEMS AND COGNITIVE FLEXIBILITY

Components	Criteria	SIMQUEST	MOODLE	KBS
Learning contents	MM1	X	X	X
	MP1	X		X
Pedagogical devices	MM2	X	X	X
	MP2	X		X
	MP3		X	
	MP4			
Human interactions	MM3		X	
	MP5		X	
Assessment	MM4		X	X
	MP6			

The important point we make here is that the set of criteria, learning tools, and authoring tools we proposed is not exhaustive. One can surely modify them, propose new ones, or even reject part of them, according to his or her personal interpretation of learning conditions fostering CF.

In earlier work [11], we also looked into a certain number of ICT-based adaptive learning systems (Table II) with respect to the five adaptation techniques identified in section III: AHA [13], KBS [20], ELM-ART [29], and PHelpS [19]. From Table II, we may conclude that adaptation support in COFALE is more or less comparable to that present in those systems. None of the analyzed systems, however, provides the course designer (with little informatics expertise) with truly easy-to-use authoring tools, such as the tools supported by COFALE, to implement adaptation support in an effective manner.

TABLE II.
EXISTING LEARNING SYSTEMS AND ADAPTABILITY

Adaptation techniques	AHA	KBS	ELM-ART	PHelpS	COFALE
Learning contents	X	X	X		X
Pedagogical devices		X	X		X
Communication support				X	X
Problem-solving support			X		
Assessment			X		

VII. CONCLUSION

CF is an important facet of constructivism [28]. From the development and validation of COFALE, a new domain-independent e-learning platform, we may conclude that our approach, based on *operational criteria*, makes the design and use of ICT-based learning environments supporting CF *straightforward* and *effective*. Indeed, the course designer can use the set of criteria for CF as a useful pedagogical framework (i.e., a checklist) and the platform COFALE as an easy-to-use technological means to create "courses" exhibiting the desired characteristics of CF.

Adaptation support is a critical characteristic in e-learning [6, 7, 24]. In this paper, we have also shown how to use authoring tools supported by COFALE to implement a certain number of basic adaptation techniques often mentioned in ICT-based adaptive learning systems.

We believe that our operational approach could also be used to exploit other facets of constructivism (e.g., problem solving) and other adaptation techniques (e.g., problem-solving support) to design more completely constructivist and adaptive learning environments. It should be noted that making a learning platform both domain-independent and able to support problem solving must be hard because problem solving is domain-dependent [29]. A possible way is to make the platform open enough so that one can integrate a specific software component (e.g., a problem-solving support component) into the existing platform without direct intervention of the software developer.

Although a preliminary evaluation of COFALE has showed several encouraging results, we shall conduct more long-term studies to know the full extent of how adaptive learning conditions fostering CF affect how students learn, especially in an e-learning context. Evaluating students' CF, however, is very hard because it is really difficult to know what happens exactly in the "mind" of an individual when he or she is learning [30]. For example, during the evaluation of COFALE, it was hard for us to find pertinent questions in order to help students to express what happens to them cognitively during their learning process. For this kind of exercise, we believe that operational criteria could be very useful, in the same way that operational criteria have been used to evaluate learning conditions. Nevertheless, proposing criteria for evaluating learners' cognitive behavior is much harder than proposing criteria for conditions of learning, because conditions of learning are observable whereas cognitive behavior is not always observable. We hope that researchers in education and cognition shall contribute to figure out this problem in the future.

A final point: What our research attempts to do is to contribute a part of making learning and instruction, in a constructivist point of view and in an e-learning context, as easy as possible.

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