COFALE: An Authoring System for Supporting Cognitive Flexibility

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Abstract

Constructivism is a learning theory that states that people learn best when they actively construct their own 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 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 e-Learning platform that could be used to build learning environments supporting cognitive flexibility, and an example of its use: the design of a course on recursion.

1. Introduction, background, and context

Constructivism and instructional design. Constructivism, as defined by Santrock [14], is an educational approach that “emphasizes that individuals learn best when they actively construct knowledge and understanding” (p. 318). Constructivist learning is a process of active construction and transformation of knowledge [4]. In recent years, constructivist beliefs and practices have been widely adopted, as evidenced by the appearance of a significant number of constructivist learning systems [13]. Many researchers accept the central assumption of constructivism as stated by Santrock; however, they derive different pedagogical implications from the same basic principles. Driscoll [11], 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 technology to exhibit constructivist principles.

Contributions. In earlier work [6, 8], we have defined a set of operational criteria for cognitive flexibility (CF), one of the important facets of constructivism. In this paper, we show that operational criteria may be used as a useful framework to exploit advanced learning technology in the design and use of learning environments supporting CF. In support of our claim, we present a new authoring system, named COFALE, in which we provide the course designer with tools and guidelines for the design of the “course” on recursion, as an example of use of COFALE.

Context for the example. The concept of recursion is very important in computing science [3]. Many teachers consider that both teaching and learning recursion are difficult because of three main reasons [1]: (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).

Structure of the paper. Section 2 introduces necessary background on CF; section 3 shows how a course designer might use COFALE to build learning environments leading to CF; section 4 reports on a preliminary evaluation of COFALE; sections 5 and 6 present our discussion and conclusion.

2. Cognitive flexibility

According to Spiro and Jehng [15], CF is “the ability to spontaneously restructure one’s knowledge, in many ways, in adaptive response to radically changing situational demands” (p. 165). We invite the reader to examine several examples of CF [7, 8, 15] to understand this concept better.

Driscoll [11] 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 [6, 8], we transformed the pedagogical principles underlying the previous two learning conditions for CF into operational criteria and we showed examples of their use. An operational criterion for CF is 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 and 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.

**MM3:** 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.

**MP3:** 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**

**MM4:** 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.

**MP4:** When facing a new concept, learners are encouraged to diversify – as far as possible – the different points of view about the topic discussed.

**Criteria for assessment**

**MM5:** 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.

**MP5:** During the problem-solving process, learners are encouraged to confront multiple ways to solve the problem and multiple possible solutions to the problem.

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

3. COFALE as an authoring system

COFALE is an e-Learning platform that supports CF explicitly. COFALE is based on ATutor [2], an open-source Web-based learning content management system (LCMS). For the purpose of the discussion, we shall assume that a “novice” learner (Alice), 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 section, we show for each criterion for CF, how a course designer (Tom) uses Web-based authoring tools provided by COFALE to present Alice with learning situations satisfying the corresponding criterion. Because of limited space, we invite the reader to explore [8] to understand COFALE’s instructional design tools better.

**Criteria MM1 and MP1.** To help Alice understand how to apply the concept of recursion in different contexts (criterion MP1), Tom provides Alice with several learning situations. For example, 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. Creating content objects

To satisfy criterion MM1, Tom has made multiple representations available for recursion: A combination of text, images, and simulations helps Alice grasp diverse aspects of recursion better than a single text does. E.g., ATutor, thus also COFALE, provides Tom with a hypermedia tool (Figure 1) to create learning content objects (content pages) in different forms.
Criterion MM2. To encourage Alice to look further into the concept of recursion, Tom presents Alice with a number of learning activities at the end of each content page, e.g., at the end of the final page of the situation about arithmetic expressions, Alice is invited to explore related topics, to add comments, to do tests, to discuss with peers, etc.

Figure 2. Editing learning activities

<table>
<thead>
<tr>
<th>Topic</th>
<th>Description</th>
<th>ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal comments</td>
<td>Add personal comments on the current content page</td>
<td>5.60</td>
</tr>
<tr>
<td>Next Page</td>
<td>Enable the next content page using the foot or the top of the right.</td>
<td>5.60</td>
</tr>
<tr>
<td>Panel Topics</td>
<td>Enable related concepts or situations, see also the menu “Related Topics” on the right.</td>
<td>5.60</td>
</tr>
<tr>
<td>LearningObjective</td>
<td>Return to exactly related content pages using the menu “Related Topics” on the right.</td>
<td>5.60</td>
</tr>
<tr>
<td>Content &amp; Comments</td>
<td>Add examples, concepts, and comments related to the current learning objective.</td>
<td>5.60</td>
</tr>
<tr>
<td>Other Resources</td>
<td>Explore other resources related to the current learning objective.</td>
<td>5.60</td>
</tr>
<tr>
<td>Plant Learning hypertext</td>
<td>Enable peer learning spaces to see how they began the current learning objective.</td>
<td>5.60</td>
</tr>
<tr>
<td>Tests</td>
<td>Test the tests related to the current learning objective.</td>
<td>5.60</td>
</tr>
<tr>
<td>Discourse</td>
<td>Include with peers about the current learning objective.</td>
<td>5.60</td>
</tr>
<tr>
<td>Collaboration</td>
<td>Work in groups to find solutions for common problems related to the current learning objective.</td>
<td>5.60</td>
</tr>
</tbody>
</table>

Figure 3. Defining pages related to an activity

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 Alice with a hyperlink to the activity (i.e. “Examples & Summaries”).

Criterion MP2. To encourage Alice to explore related topics (e.g. simple text search) while she 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 (COFALE) 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 Alice in her learning hyperspace (see also [7]).

Figure 4. Defining “Related Topics” relations

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

Criterion MP4. COFALE also satisfies this criterion without Tom’s intervention, e.g. it provides Alice with an empty table so that she can state her 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 (thus also by COFALE) to create forums for learners to exchange, e.g. 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 (COFALE) to foster students’ learning.

Criterion MP5. To help Alice elicit peers’ point of view during discussion, Tom uses tools provided by COFALE to introduce a list of general questions proposed by educational theorists [16] and a list of domain-specific questions. E.g.: 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 (COFALE) provides Tom with a test manager (Figure 5) so that he can create individual tests, e.g., 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.

Figure 5. 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). Alice and her peers are invited to use this collaboration hyperspace to confront, examine, and compare different recursive solutions to a given problem.

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 evokes 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 given directory, then in its sub-directories.

4. Preliminary evaluation of COFALE

A 2-week-long study was performed to formatively evaluate the recursion course we designed using COFALE [8]. 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 the COFALE group explored COFALE and the control group a chapter about recursion of a reference book (within 1 hour).

Several encouraging results were reported on learning with the help of COFALE. Students in both groups mastered recursion to a significant degree. The COFALE group’s learning behavior, however, seems 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.

5. Discussion

To understand COFALE as a learning environment supporting CF better, one should explore our earlier work [7]. To understand learning tools and authoring tools supported by COFALE completely, one should examine the dissertation of a researcher of ours [8]. To explore the COFALE open-source project (including the course on recursion), one should visit the website http://openresources.info.ucl.ac.be/cofale.

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 COFALE supports many learning activities without intervention of the course designer. It should be noted that, in practice it is not necessary to always satisfy all of the criteria for CF: In certain contexts, e.g. in introductory learning, satisfying a half of the criteria might be sufficient enough to help students attain the learning objectives effectively.

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, e.g. the tools shown in Figures 2 and 3 could be used in the design of any “courses”.

For the implementation of COFALE, we have modified several components of ATutor and added a number of learning and authoring tools. Our contribution to ATutor is about 20 percent of the source code (6 person-months of programming work). We have
selected ATutor among many open-source LCMSs because it makes it easy to add pedagogical devices exhibiting the desired characteristics for CF.

In earlier work [8, 17], 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 [9], a Moodle features course by Moodle [10], and a Java course by KBS [12]. The analysis (Table 1) showed that there are many different ways to create ICT-based learning conditions fostering CF and that the course designer should take into account the quality of criteria satisfaction rather than only the number of satisfied criteria.

Table 1. Existing learning systems and CF

<table>
<thead>
<tr>
<th>Components</th>
<th>Crite-</th>
<th>SimQuest</th>
<th>Moodle</th>
<th>KBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning contents</td>
<td>MM1</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>MP1</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pedagogical devices</td>
<td>MM2</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>MP2</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>MP3</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>MP4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human interactions</td>
<td>MM3</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MP5</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assessment</td>
<td>MM4</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MP6</td>
<td>X</td>
<td></td>
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</tr>
</tbody>
</table>

6. Conclusion

CF is an important facet of constructivism [15]. 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 learning environments supporting CF straightforward and effective. Indeed, the set of criteria for CF provides a useful framework (i.e. a checklist) for the course designer and the teacher to design and use "courses" exhibiting the desired characteristics of CF.

We believe that our operational approach could also be used to exploit other facets of constructivism (e.g. problem solving) to design more completely constructivist 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 [5]. 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 learning conditions fostering CF affect how students learn, especially in an e-Learning context.

7. References