Advanced learning methodology, based on action research and collaborative work for the teaching of high performance computing

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Abstract. The Advanced Learning Methodology (AdLM) is presented as an improvement of the collaborative work assisted by the teacher, in order to strengthen the competences in the development of teamwork and close gaps in the Action Research (AR) process. To implement the methodology, a short course on High Performance Computing (HPC) is presented as a learning object. This short course is oriented to a group of Systems Engineering students of the University of Pamplona (Colombia). In order to validate the progress of knowledge appropriation through AdLM, an evaluation or test is applied at three different times: at the beginning, in the intermediate and at the short course’s ending. The difference between each test represents a knowledge gap as a quantitative measure of knowledge appropriation. The results show that AdLM provides an alternative in the active and collaborative participation of the students, and additionally proposes a quantitative measurement of the appropriation of knowledge progress.

1. Introduction

Action Research (AR) is the process in which participants examine their own educational practice in a systematic and careful way, using research techniques [1]. AR is presented as a tool to bring processes of appropriation of knowledge in a participatory and democratic way [2]. AR provides practicality to research; using multiple techniques aimed at improving the traditional teaching method. AR is a strategy in modern research for the creation of knowledge, which involves three fundamental elements: action, research and participation. Fundamentals that favor the adoption of measures to increase efficiency and effectiveness, within a sustainable context, promoting a democratic social change in the generation of knowledge.

In [3] the needs of orientation and constant supervision of the teacher in research processes are identified in the learning activities for the implementation of the AR process. This paper presents an improvement of the collaborative work assisted by the teacher, in order to strengthen the competences of teamwork development and close the gaps in the AR process. The methodology proposed by AdML complements the efficiency presented by the use of a collaborative learning tool, with AR. The expected proposed research results’ are the development of critical thinking, in a collaborative environment, which fosters the motivation to process new information, as a first strategic phase for students, laying the foundations for the generation of new knowledge.
The learning object for the implementation of AdLM, is a short course of High Performance Computing (HPC): technique for the development of simulations and solutions to complex problems in the field of Computer Science [4–6]. The new demands of solving complex problems and advancement in computer science make for paradigm of shared memory and parallel programming to become important disciplines in computer science [7]. The applications for development of research with high performance systems are presented in: Computer Science [8]; Earth Sciences [9–12]; and in many scientific disciplines. The HPC short course is presented as a part of the University of Pamplona (Colombia) Department of Systems Engineering Operating Systems course. The specific objectives to be implemented in the methodology are: 1) understand the design and configuration of the HPC Beowulf cluster, 2) understand and apply knowledge about high performance concepts, 3) collaborate and coordinate group efforts to achieve the objective proposed, 4) effectively use and communicate HPC knowledge and information and its application. The contents of this paper are presented below. In section 2, references are made to papers related to state of the art learning methodologies. In section 3, a general description of the proposed methodology is presented. In section 4, results are presented and in section 5, conclusions.

2. Related works
In [13], the authors present an active methodology in the learning process in memory hierarchy. The analysis proposes an experimental environment consisting of systems with different configurations. In the research, no metrics are presented to evaluate the effectiveness of the methodology, that is, the appropriation of knowledge. However, students improved significantly in parallel learning application metrics.

In [14] the basis of the AR process is the opening of a communicative space as strategy to achieve the group’s development, where the stages of inclusion, control and exchange have progressively increased. The success or failure of the application of the AR process depends on: 1) the way in which access is established, 2) how participants and co-investigators commit themselves from the beginning of the process and 3) the use of the communicative space.

To improve and innovate university education, the authors of [15] propose the application of AR in the engineering area, emphasizing the development of practices led by a research professor. The milestones mentioned by the authors are: research teacher’s motivation to integrate investigation and teaching; improvement of academic programs and student learning, and advances in educational knowledge.

In [3], the authors present AR results, in a CAD course at the Juan Carlos I University. The main objective of this paper is to analyze learning outcomes obtained by implementing this inclusive teaching-learning methodology, in order to find ways to improve student learning. The results indicate that it requires greater dedication from the teacher given the materials’ quality and complexity for self-learning, among others.

This research is developed by taking into account the mentioned authors’ observations and conclusions presented above. To implement AdLM, groups of students are formed and computer tools are used in collaboration environments. To measure the appropriation of knowledge, or quantitative effectiveness, a survey type evaluation measure is carried out. The evaluation consists of 20 HPC related multiple-choice questions, applied at 3 different times. The First is the baseline. The Second is done halfway through the course. The Third and last takes place at the course’s ending. The three evaluations measure the appropriation of knowledge.

3. Methods
Figure 1, presents the proposed advanced learning methodology (AdLM), comprising: planning, guide document and collaborative work.
AdML is based on the AR learning cycle’s benefits and is complemented by an illustrative guide document for each step of the learning object. The AR learning cycle has as components the planning, the action, the reflection and the observation. In AdML it is proposed that the components of AR are incorporated into a research efforts in collaborative environments. Collaboration is a key factor in building quality education. People thrive in environments allow them to communicate and work together freely. When the environment for objective achievement revolves around collaboration, team members naturally feel part of something larger than themselves. The best way to go from an individual mentality to a group mentality is to show each team member that their active participation offers better results. In the collaborative learning process, the participants foment:

- Cohesion between group members;
- Innovation;
- Group objectives are established;
- Expectations are communicated;
- A clear and convincing cause of their activities is created, among others.

3.1. Learning object
A HPC short course is presented as a learning object to the students of the University of Pamplona’s (Colombia) Department of Systems Engineering Operating Systems course. The short course’s objective is to develop the following competences:

- Understand the design and configuration of the HPC Beowulf cluster;
- Understand and apply knowledge about high performance concepts;
- Collaborate and coordinate group tasks to achieve the proposed objective;
- Effectively use and communicate HPC knowledge information and its application.

The first two competences are addressed through master classes with slide presentations, complemented by workshops led by the research professor. The short course includes necessary tools, computer equipment, software libraries, high performance material, Linux operating system software, among others.

3.2. Planning
Table 1 presents the time dedicated to each specific activity (theory, workshops, personal and collaborative work) and the corresponding HPC short courses evaluation. For each activity the number of hours, the time of attention and the individual work hours is specified. Additional activities proposed by the teacher are also presented with the number of hours / week for each specific activity.

Activities in table 1 are described below:

- Theory, represents sessions of master classes: introduction of general HPC concepts, complemented with multimedia material;
• Practical sessions, workshops and pedagogical/instructional materials for the Beowulf Clusters installation and configuration are included;
• Supervision, the expert teacher provides individual assistance on comments / question / observations / suggestions from the students;
• Teamwork, formed by students, aims to develop a research report using online collaborative work tools: the expert teacher guides a research topic on basic HPC concepts;
• With the support of the teacher, each student spontaneously and voluntarily, chooses or selects a basic concept (s) for the development of the research topic.

| Table 1. HPC short course: Activity planning. |
|---------------------------------------------|
| Activity         | Classes work | Individual work (hrs/week) | Specific activity (Proposed by teacher) |
| Theory           | 4            | 0                          | Theory sessions                         |
| Workshop         | 2            | 0                          | Practical sessions                      |
| Tutorship        | 1            | 0                          | Personalized assistances                |
| Teamwork         | 0            | 2                          | Collaborative work                     |
| Individual work  | 0            | 2                          | Research                                |
| Test             | 0            | 2                          | Three test are performed                |

3.3. Guide document
To develop the workshop, students have a guide document, which facilitates the step by step of each task to be developed. The guide document explains the steps to install and configure a Beowulf Cluster. Students must perform cluster performance tests upon finishing installation and configuration. Cluster performance tests are performed through different experiments that run benchmarks or test applications. All activities are carried out under the supervision of the research teacher.

With the experiments, students can complete the results’ analysis, taking the concepts of HPC into account, such as: acceleration, scalability, performance, fine granularity, coarse granularity, among others. In addition, the guide document describes the steps for collaborative work development in a work team formed voluntarily.

3.4. Collaborative work
The purpose is that students in their process of research and appropriation of knowledge may write a documentary report together and in collaborative manner. The report shows the development of the research’s learning object, describing each step of the workshops’ progress and the research developed. The preparation of the research report are done through collaborative work, obtaining all the benefits of teamwork, such as:

• Specialize in the development in a part of the problem;
• Fomentation of creativity and learning;
• Stress reduction;
• Increase in efficiency and productivity;
• Performance improvement;
• Update on the use of information and communication technology (ICT) tools.

This component of AdLm allows teamwork organization, development and editing. It is directly supervised by the students. Additionally, active learning is encouraged since the student is part of the problem, while observing, editing, planning, considering opinions and acting directly in the development of teamwork.
3.5. Progress evaluation
The process concludes with evaluation through a multiple choice test. To measure the progress of knowledge appropriation by applying the methodology, the evaluation or test is applied in three different times: at the beginning, in the intermediate and at the short courses ending (The test is the same applied in three different times).

4. Results
This section explains the method for designing experiments and analyzing results. The progress evaluation is accounted using the method for knowledge appropriation measure. The target population is superior education students, from the systems engineering program of the University of Pamplona, Colombia. Teaching topics focused on the basic concepts and application criteria needed to strengthen students’ professional competencies in the understanding of HPC.

4.1. Used indicators
The calculation components of the learning measurement indicator, obtained using AdML, are described below.

4.1.1. Data capture: The experimental design is made to nine (9) students to whom it is initially applied a multiple-survey type test. The size of the chosen sample is equal to the population. The test consists of 20 questions prepared by the research professor, where each student selects the correct answer in a group of 4 (four) sentences. These tests are taken online at 3 different times (the same test in the three times). The application times are at the beginning, middle and the short course’s ending. The duration of the short course is 12 weeks. Table 2 presents the selected topics to be evaluated. The topics are related to HPC.

| N. | Topics                      | N. (cont.) | Topics (cont.)          |
|----|-----------------------------|------------|-------------------------|
| i  | HPC features                | xi         | Cores and multi-cores   |
| ii | Paralleling programming     | xii        | Cluster beowulf         |
| iii| CUDA                        | xiii       | MPI                     |
| iv | Threads                     | xiv        | GPU                     |
| v  | Coarse granularity          | xv         | Fine granularity        |
| vi | Data mining                 | xvi-       | Shared multi processors |
| vii| HPC algorithms              | xvii       | API (parallels tools)   |
| viii| Shared memory paradigm      | xviii      | Flynn’s taxonomy        |
| ix | Cluster computing configuration | xix     | Software solutions      |
| x  | OpenMP                      | xx         | Hardware solutions      |

4.1.2. Calculation of the knowledge gap: the percentage measure of knowledge appropriation (% tKG) through AdML is presented in equation 1.

\[
\% tKG = \frac{(TKC - \sum_{i=1}^{20} PCK_i)}{PCK} \times 100 \tag{1}
\]

• Percentage of the Knowledge Gap (% tKG): represents the distance (absolute difference), between the maximum possible knowledge acquired by the universe of students (100%), and is evaluated in each test. It is a statistic that adds the residual or the failure of each test. It can be used to focus the methodology on topics not reached by the student. It is the main indicator of the design of the experiment;
• Total Knowledge Certainty (TKC): represents a constant and is obtained as the result of
the highest possible certainty in the test in the entire universe. It can be understood that
this value is obtained from the simple product among the factors, the number of subjects
evaluated (20) and the maximum certainty for each topic (100%);
• Particular Certitude of Knowledge (PCKi): represents the certainty of each test, taking into
account the universe of participants and the questions on the 20 topics. It is considered that
each topic could reach a certainty of up to 100%. It is a simple statistical sum of certainty.

4.1.3. Results obtained from the experimentation scenario: Table 3 present the 3 times
evaluated, that is, the progress of knowledge appropriation through AdLM. Additionally, it
presents the particular percentage of knowledge gap for each moment in front of a particular
topic. I, II and III represent different times or moments to apply the test.

Table 3. Particular certitude of knowledge (%tKG) for each moment of test and summary.

| Topics | I    | II   | III  | Topics (cont.) | I    | II   | III  |
|--------|------|------|------|---------------|------|------|------|
| i      | 0.0  | 69.2 | 55.6 | xi            | 62.5 | 66.7 |
| ii     | 33.3 | 22.2 | 44.4 | xii           | 50.0 | 66.7 |
| iii    | 100.0| 55.6 | 37.5 | xiii          | 62.5 | 33.3 |
| iv     | 66.7 | 44.4 | 50.0 | xiv           | 44.4 | 66.7 |
| v      | 33.3 | 11.1 | 44.4 | xv            | 22.2 | 66.7 |
| vi     | 44.4 | 22.2 | 77.7 | xvi           | 50.0 | 58.8 |
| vii    | 77.8 | 44.4 | 66.7 | xvii          | 50.0 | 58.8 |
| viii   | 22.2 | 44.4 | 88.9 | xviii         | 25.0 | 72.2 |
| ix     | 0.0  | 11.1 | 44.4 | xix           | 22.2 | 66.7 |
| x      | 55.6 | 22.2 | 22.2 | xx            | 12.5 | 58.8 |
| summary| 50.6 | 45.6 | 41.2 |

Figure 2. Knowledge gap %tKG: The gap is progressively reduced.

Table 3 shows a summary of (% tKG). The summary indicates that AdLM has closed
a knowledge gap of 9.35%. That is, students have learned 9.35% more, respecting initial
knowledge. Samples were taken at 4 week intervals and applied to the same control volume.
For the 20 topics evaluated in the test, it can be observed that the students had 49.5% as a
reference for knowledge appropriation. Mainly due to the fact that the population is composed
of students with superior education in Systems Engineering. Secondly, the population possesses
a knowledge appropriation of 54.4%, and at the third time, a knowledge appropriation of 58.8%
among the subjects evaluated. Figure 2 shows that (% tKG) is progressively reduced as the
methodology’s implementation progresses.
5. Conclusions
AdML is proposed as a methodology that complements the AR process and collaborative work in universities and education institutions in general.

Figure 2, shows that the change rate of the knowledge gap (% tKG) is smooth and linear, which allows us to conclude that the proposed methodology contains an intrinsic and didactic way of transmitting and teaching knowledge.

The knowledge gap results indicate slight progress in closing the gap of 9.35%. This is because the population selected for the experiment is highly qualified (students of systems engineering). In order to observe changes in a scenario where the closing of the gaps is strong and significant, it is proposed to apply AdML to a group of students with non-advanced knowledge or with different topics and / or research topics.

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