Learning integer numbers representation by means of an Aronson's puzzle

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Abstract— This work presents an experience developed with first year students of Grade on Computers and Grade on Telecommunications at Universitat Politècnica de València. The academic programme of both grades includes an introductory course to computers, called Computer Fundamentals. The course is different for each grade, but they share some topics.
One of these common topics is data representation in computers, including positional numeral systems and representation of integer and floating point numbers, among other data representation like characters.
In order to give students the opportunity to train soft skills and also to give a chance to enjoy learning, the lessons related to integer numbers representation in computers was planned as an Aronson's puzzle. This work presents a detailed description of six experiences developed in academic years 2013/14, 2014/2015 and 2015/16. Results from two satisfaction surveys are presented

Keywords— *Aronsons's puzzle; Integer numbers representation; peer assessment; self-assessment; collaborative learning;*

I. INTRODUCTION

The course Computer Fundamentals is taught during the first semester of the first year of Grade on Computers and Grade on Telecommunications at the Universitat Politècnica de València. In fact, it is not the same course, because there are important differences between the objectives, topics, assessment, and academic organization of the course for each grade. The course for computer engineering students starts with the digital design of combinational and sequential circuits [1], and ends with an introduction to Instruction Set Architecture (ISA) and assembly programming [2], while the course for telecommunication engineering students focuses in the study of the computer's functional units [3]. The course for grade on computers is 6 ECTS [4] while the course for grade on telecommunications is 4.5 ECTS. Table 1 shows the main characteristics of both courses with a brief list of covered topics.

Both courses include a unit dedicated to data representation in computers. At the end of this unit students should be able to represent natural numbers in different radices, integer numbers using several conventions, real numbers in IEEE754 standard for floating point, and be skilled in other common schemas like BCD.

The unit about data representation is divided into lessons, and the lesson "representation of integer numbers" discusses the different conventions used in modern computers to represent integer numbers [5]. When students finish this lesson they must be proficient representing integer numbers in three conventions: Signed Magnitude, Two's complement, and Excess-K. Moreover, students must be able to carry out simple arithmetic operations like addition and subtraction using two's complement representation. Finally, students should be able to decide the most appropriate convention for different scenarios or applications.

This paper presents an experience developed with this particular lesson about the representation of integer numbers. In order to allow students to learn in an autonomous way, and at the same time in a cooperative way, and gain cross-curricular skills, this lesson is studied by means of an Aronson's jigsaw or puzzle. Also, embedded in the puzzle are activities of self-assessment and peer-assessment that may improve the learner autonomy [6].

Next section presents the schedule of the puzzle within the course schedule and previous skills acquired by the students. Later, materials employed and activity organisation are described in detail. Section experiences presents the different experiences developed. Finally conclusions and future work are presented.

II. COURSE CONTEXT

Before starting to study the representation of integer numbers, students of both grades work with numeral systems in different radices, so they master conversion to/from binary for natural numbers, as well as basic arithmetic operations like addition and subtraction in radix 2. In fact, students of the grade of computers have spent close to ten weeks thinking in binary and hexadecimal.

In its first version, the puzzle was designed to study four representation conventions or schemas:

- Signed magnitude.
- Ones' complement.

- Twos' complement including basic arithmetic.
- Excess-K.

Because of changes in courses organization the schema called one's complement was removed from course topics, and therefore it was removed also from the puzzle for the third and subsequent implementations.

After the result of the experiences detailed below, arithmetic in two's complement was removed from the puzzle and taught in a traditional way in the last three experiences.

III. The Aronson's puzzle

Aronson's puzzle was created more than 40 years ago to reduce racial conflicts in United States of America schools. But this learning method quickly showed that not only helps to reduce conflicts, but also improves student's outcomes and satisfaction [7]. The simplicity of the method and its worth to both learn course-specific and cross-curricular skills makes it proper for any grade and subject.

In brief, the steps to implement an Aronson's puzzle are the following:

Divide the topic, task or objective into segments. Create groups of students, called puzzle groups, with as many students as segments. Then, each student receives documents related to only one segment, and works with them in an individual way. The next step is to create the group of experts, one group for each segment. All students who previously worked in a particular segment meet up with their classmates who worked the same segment, to improve his or her knowledge and skills about the segment by means of discussion and collaborative work. When they have become *experts* they come back to the original puzzle group, instructing to, and learning from, the others members of the puzzle group. Finally they carry out an assessment about the topic of the puzzle. During all the process, teacher must observe groups and give some indication if needed.

There is no unique way to implement an Aronson's puzzle. Emphasising particular activities of the puzzle will focus the learning of students in course-specific or cross-curricular skills. Representation of integer numbers, a course-specific skill, is the main goal of the learning process pursued in this work. Therefore, some common practices and elements in Aronson's puzzle, like naming leaders for the groups, are not implemented in this experience.

IV. Documents and Organisation

In order to be successful the activity has to be prepared in advance and carefully planned. This includes materials for students and also for the teacher. The author created all materials ad-hoc for this experience. Next subsections describe the documents the students use during the puzzle, the documents used by the teacher, and the tasks developed during all the activity. Find the complete documents at http://hdl.handle.net/10251/49683

A. *Documents for the students*

It is clear that students need documents that show the knowledge and topics they have to learn, and tools to train the skills they should acquire. It is also convenient to give the students some indication about soft skills or attitudes they can improve during the activity, and also tell them how they should behave during the different tasks of the activity.

But it is very important to give the students a guide about the puzzle. For some students this is the first time they play an Aronson's puzzle. Even if students know this learning technique, each experience is different and requires detailed instructions. The guide must include the schedule of activities to be developed. A brief explanation about the reasons to carry out these activities may help students to get involved in the puzzle.

TABLE 1: Main characteristics of the two courses Computer Fundamentals.

	Grade on Telecommunication	**Grade on Computers**
ECTS	4.5	6
Semester	1	1
Lecture	1.5 hours x 2 per week	1.5 hours x 2 per week
Laboratory	1.5 hours x 4 per semester	1.5 hours x 10 per semester
Weeks	14	14
Total students	≈160	≈400
Number of groups	4	10
Topics	— Numeral systems. — Data representation. — Processor structure. — Memory system. — Input/output system.	— Numeral systems. — Digital design. — Data representation. — Introduction to Assembly language.
Assessment (% of total mark)	— Three in-class exams. (70%) — Exercise resolution with peer-assessment (15%). — Laboratory assessment. (10%) — Five take-home exams (10%)	— Two in-class exams (70%) — Exercise resolution with peer-assessment (10%). — Laboratory assessment. (20%)

The documents delivered to the students are:

- Instructions: list of documents that each student must receive, directions for group creation, plan of activities to carry out and estimated time to finish each of them.
- Educational paper: There are four documents, each one explaining one convention of representation: Signed Magnitude, One's Complement, Two's complement and Excess-K. Documents include examples and exercises with their solution. In the first version of the puzzle, employed in the three first experiences, the document related to Two's complement included also basic arithmetic for integer numbers.
- Set of exercises: There are four documents, one for each representation convention, with a collection of related exercises. Solutions to exercises are not included, but assessment criteria to allow peer-assessment are included.
- All-in-one set of exercises. A collection of exercises related to the four ways of integer representation. The collection includes exercises about range of representation, sign extension, converting from decimal to any convention and vice versa, and addition and subtraction only for numbers represented in twos' complement. Solutions are not delivered to students.
- Satisfaction survey. It is a simple questionnaire with four multiple-choice questions and blank space for free comments.

It is important to remark that during the activity, each student receives only a pair paper-exercises related to one of the four representation schemas. This way, five documents are delivered to each student: instructions, educational paper about one representation convention, set of exercises for the same convention, all-in-one set of exercises, and the survey about the activity.

Once the activity is finished, students will get free access to all documents of the puzzle but solutions to exercises. Solutions to convention-related exercises and all-in-one exercises are never available. If a student wants to check their solutions, he or she may ask teacher for office hours.

B. Documents for the teacher

Designing and preparing this activity requires time and a careful consideration, usually a long time before the activity is performed. Conclusions and decisions from this previous phase should be annotated. Therefore, it is important to create a set of tools that allows the teacher to react quickly and in a coherent way with the set of goals during the development of the activity. Also recording events, feelings, and the actual time required for the different tasks will help to improve the activity in future implementations.

The list of documents for the teacher is:

- Objectives. A summary of the learning goals the teacher wants to achieve with this activity.
- List of material and documents that must be delivered to students, and when to deliver them.
- Schedule of activities, including details about how to organize students, tasks they should carry out, and expected time to finish each task.
- Empty table to annotate the convention each student has worked with and the puzzle group he or she belongs to.
- Log book with empty tables to easily record the actual time of activities and important events.

C. Activity organization

The puzzle is developed in the classroom during hours assigned to lecture and resolution of exercises, which was the way this topic was previously taught.

Below is shown the list of activities and the estimated time length. This length is the teacher's estimation before the first experience.

1. Present the activity, deliver the instructions and create puzzle groups formed by four students. 15 minutes.

2. Deliver of educational papers. 5 minutes.

3. Students work individually the convention they have received. Each student solves proposed exercises in the educational paper and checks its solutions with given solutions. 20 minutes.

TABLE 2: MAIN DATA ABOUT THE SIX EXPERIENCES.

	Exp. 1	**Exp. 2**	**Exp. 3**	**Exp. 4**	**Exp.5**	**Exp 6**
When	September 2013	November 2013	September 2014	November 2014	September 2015	November 2015
Grade	Telecom.	Comp.	Telecom	Comp.	Telecom	Comp.
Num. of students	68	36	17	33	19	39
Answers to: First survey Second survey	 25 -	 15 -	 14 -	 27 -	 17 15	 26 10
Contents	Four conventions, including 2sC arithmetic	Four conventions, including 2sC arithmetic	Three conventions, including 2sC arithmetic	Three conventions, with no 2sC arithmetic	Three conventions, with no 2sC arithmetic	Three conventions, with no 2sC arithmetic

4. Creation of four groups of experts. Each student joins the classmates that have worked the same schema of representation. Students discuss the main ideas of their convention and clarify doubts. 20 minutes.

5. Within the expert group, each student solves individually the set of exercises related to its convention. 10 minutes.

6. Within the expert group, students exchange their exercises to carry out a peer-assessment. There are no solutions available, but students may discuss and interact. 10 minutes.

7. Reactivation of puzzle groups. At this moment, each member of the puzzle group is an expert in one of the four conventions. All students come back to the original puzzle group and train the other colleagues. 60 minutes.

8. Solving the all-in-one collection of exercises. Within the puzzle group, this set of exercises is solved in a cooperative and collaborative way. Each group should provide a unique document with a solution made by consensus. There are neither external solutions nor external assessment. 20 minutes.

During the activity, mainly when delivering material, the teacher gives instructions about the next task and states the objectives. While students are working, the teacher may answer questions from students and solve doubts in an individual way, avoiding to lecturing to the whole class.

V. EXPERIENCES

The puzzle has been used six times: three times in September (2013, 2014, and 2015) with students of telecommunications, and three times in late November (same academic years 2013, 2014, and 2015) with students of computers. TABLE 2 shows main data about the groups for the six experiences, and also show the contents of the puzzle. Changes in content across the years are described later.

A. *Development of the experiences*

The three groups of students of grade on computers were homogenous, that is, similar number of students, similar average academic level, and taught in the same language.

The three groups of students of grade on telecommunications were very different. In 2013 the group was very large, with differences in academic level within the group (from excellent to medium), and this group was taught in Spanish. In 2014 and 2015 the groups were very small, with high academic level and taught in English.

TABLE 3 shows detail of time needed by students to make the most important activities included in the puzzle, and the total time spent in the whole activity. Before the first experience, the teacher estimated the time students will spend in each task of the puzzle: none of the predictions were right, sometimes overestimating and others underestimating the actual time employed by the students. Although time estimation was wrong the author thinks that an inaccurate estimation is better than no estimation at all.

However, the main problem related to time is not an erroneous estimation that may be corrected in future implementations (indeed it was adjusted after each implementation). Also the difference between time employed by students of different grades or even different classes of the same grade is not a problem if the puzzle is planned with some flexibility in mind.

The main problem is the difference, within a class, in the time employed by individual students or groups of students in some activities because of the piece or segment of the puzzle they have to work with. This happens in the three first experiences, and was corrected for the fourth and following experiences.

The problem was in the two's complement convention. The complexity of four conventions is similar and low for university students. But two's complement included basic arithmetic because this is the way integer numbers are represented and operated in today computers, so it is an important topic of the course. This arithmetic is not complex, the topic is limited to addition and subtraction, but the student has to learn and solve exercises that the students working other conventions have not.

This way, during the individual work, the member of each puzzle group who is working with the two's complement schema is the last to finish, so the group of experts in two's complement is the last to be created. Even more, the collection of exercises about two's complement is longer than collection

TABLE 3: TIME SPENT IN MAIN PUZZLE ACTIVITIES (MINUTES) FOR EACH EXPERIENCE.

	Exp. 1 Comm. 2013	**Exp. 2 Comp. 2013**	**Exp. 3 Comm. 2014**	**Exp. 4 Comp. 2014**	**Exp. 5 Comm. 2015**	**Exp. 6 Comp. 2015**
Individual work	35	40	50	35	30	40
Work within expert groups	55	35	40	30	40	30
Learning in puzzle group	25	30	30	25	40	40
Solving final exercises	50	45	60	35	35	45
Total time from start to end	210	160	190	130	145	155

of exercises for other schemas, so it takes longer to solve and assess them than the others. Because the delay to start the work within the group of experts and adding its overload in front of the other conventions, the expert group on two's complement finished up to 20 minutes later than other groups. The puzzle groups were not be created until all the members finish their work in the experts groups, so most students were waiting for the two's complement experts group to finish before to start working in the puzzle group.

When students are in classroom and have nothing to do, the situation may become out of control, even with university students, that quickly start to talk loudly and therefore disturbing other students. Allowing students leaving the classroom is a solution, but students who have not yet finished feel uncomfortable while they are working and their classmates are enjoying a break. In any case, students may think that something was incorrectly planned and lower their satisfaction with the activity. And they are right.

An alternative is to add basic arithmetic to all the representation conventions, increasing and balancing the workload for all students. Sadly, only two's complement arithmetic is included in the objectives of the two courses, and hence other arithmetic is not assessed in exams, so students may claim that studying them is a waste of time, and the author would agree with students to some extent.

Finally, after three experiences, two's complement arithmetic was removed from the puzzle in the last three experiences. The total time of the activity was reduced with respect to the previous year (see TABLE 3) but the most important was that all students and groups finished their activities within a gap of five minutes. This helps to keep the attention of students in the work and maintain the dynamic of the puzzle.

Therefore, TABLE 3 should be analysed carefully, because there are two different puzzles in it: the three first experiences including two's complement arithmetic, and the last three without it. Despite this fact, TABLE 3 shows that there are significant differences in the time spent by different groups of students, without regard of the grade they are enrolled, so this activity must be planned in a flexible way.

B. *Assessment of students' work*

Related to specific-course skills, the assessment of students is carried out three times. First, during the individual work students solve some basic exercises. The document where the representation schema is explained includes the solution to these exercises and this way the student can perform a self-assessment [8].

Second, when they are working in the experts group there is an explicit peer-assessment of skills related to the representation schema they are experts. Because the assessment is face-to-face, a debate between students may exist, raising the value of peer assessment [9].

And third, there is an implicit peer-assessment of skills related to all the conventions when they are working the last collection of exercises in the puzzle group. Because they have to solve the exercises in a cooperative way and get a unique solution, there is a continuous assessment of the work of each group member. In [10], this is called peer feedback instead of peer assessment, because there are no grades or marks, only comments between peers.

Specific-course skills will be assessed and marked later, using the same instruments defined for other units of the course and together with students of all classes.

Related to soft or cross-curricular skills, there is no assessment. Students are not asked about the work of their colleagues in the groups, and teacher does not record data about the behaviour or involvement of students in the activity.

C. *Assessment of the experience*

Two surveys were used to assess the experience. The first survey was answered by the students just at the end of the activity, before they leave the classroom. In fact, this survey was included in the puzzle instructions. The second survey was delivered to students after marks related to puzzle topics were available. Only the students of year 2015/2016 (the last two experiences) answer this second survey.

For the first survey, the students have to answer four questions using a Likert-type scale [11] [12]. The four questions, the four possible answers and the percentage of answers for the six experiences are shown in TABLE 4.

The first result from the survey is that most of the students are highly satisfied with this activity in all aspects. The most appreciated part of the activity is the delivered documents. The students also highly appreciate the usefulness of the activity, although some of them have their doubts. Regarding the organization of the activity, students clearly show that it must be improved. And finally, criticism and doubts arises when students think about working others units of the course in the same way.

The second survey was delivered using the virtual learning environment (Poliformat) of the university. The students

TABLE 4: PERCENTAGE OF ANSWERS TO THE FIRST SURVEY FOR THE SIX EXPERIENCES (TOTAL ANSWERS 124).

	Nothing	Little	Sufficient	A lot
Plan of the activity is appropriate.	-	2%	42%	56%
Materials (documents, exercises) of the activity are appropriate	-	1%	28%	71%
I think this activity is useful	-	2%	33%	65%
I would like this activity to be applied in other units of this course.	-	8%	35%	56%

answer it when all marks related to integer number representation were available. Telecommunication and computer students answered the second survey three months and two months, respectively, after carrying out the activity. This survey has fourteen questions mixing different types of answers. Below is the list of questions and possible answers, and the percentage of answers for (telecommunications students) and (computers students). No value shown means 0%

Q1. Regarding the Aronson's puzzle performed in the classroom, did you attend the whole activity?
A. No, I didn't attend at all.
B. I attended more or less half of the activity
C. Yes, I participated in all the steps. (100%) (100%)
D. I don't know / I have no answer.

Q2. Regarding the first activity of the puzzle, that is, individually read and work the representation convention, I think: if the teacher would have explained the convention I would have spent less time to learn and understand the representation convention than the time I spent to learn it by myself.
A. No, I think I spent less time working individually. (20%) (56%)
B. Yes, I think I would have spent more time working individually. (27%) (0%)
C. Anyway, I would have spent the same time. (40%) (44%)
D. I don't know / I have no answer. (13%) (0%)

Q3. Regarding the second activity of the puzzle, I think that thanks to the work within the experts' group I cleared up some ideas I didn't understand during individual work.
A. True (87%) (78%)
B. False (13%) (22%)

Q4. Regarding the second activity of the puzzle, I think that thanks to the work within the experts' group I cleared up some ideas I misunderstood during individual work.
A. True (87%) (78%)
B. False (13%) (22%)

Q5. The work within the experts' group was:
A. Not useful at all.
B. Of little use. (7%) (0%)
C. Useful. (80%) (89%)
D. Very useful. (13%) (11%)

Q6. Regarding the third step of the puzzle, that is, the work within the puzzle group, some of the members of my team didn't understand or didn't explain properly some part or even all the convention that we have to learn from him or her.
A. Yes. (40%) (67%)
B. No. (60%) (33%)

Q7. During the work within the puzzle group, explanations about other conventions from the members of the group were (in average):
A. Not useful at all.
B. Of little use. (13%) (0%)
C. Useful. (60%) (89%)
D. Very useful. (27%) (11%)

Q8. Lecturing and explaining my representation convention to the other members of the puzzle group helped me to learn it better.
A. No. (0%) (22%)
B. Yes. (93%) (78%)
C. I don't know / I have no answer. (7%) (0%)

Q9. Within the puzzle group, in the last step of the activity, we solved the set of exercises of all the conventions in the following way:
A. Each member of the group solved a part of the document and then we collected the different parts together. (7%) (11%)
B. Each member of the group solved the whole document and then we compared and checked our solutions. (40%) (11%)
C. We all together solved each exercise, discussing the way to solve it until reached a consensus. (53%) (78%)
D. None of the previous ways.

Q10. The work carried out solving the last bulletin was:
A. Less useful than previous activities.
B. As useful as the previous activities. (40%) (22%)
C. More useful than previous activities. (60%) (78%)

Q11. Taking into account the whole puzzle activity, I think I have needed less time at home to learn the representation of integer numbers because we used the puzzle.
A. No, it would have been better that the teacher had explained it in the same way than the rest of the course.
B. I think there is no difference. (27%) (0%)
C. Yes, I think the puzzle is a more efficient way to learn. (73%) (100%)

Q12. I think my exam mark has been higher because we used the puzzle.
A. No, my mark would have been higher if the teacher had been explained it in the same way than the rest of the course. (7%) (0%)
B. I think there is no difference. (67%) (44%)
C. Yes, I think I learned better and the mark is higher. (27%) (56%)

Q13. Working with the puzzle allowed me to improve my soft skills (communication, discussion, teamwork...)
A. No.
B. Irrelevant. (20%) (11%)
C. Yes. (80%) (89%)

Q14. I think it is a good idea to use the Aronson's puzzle. You can choose none, one or two answers.
A. No. (13%) (0%) (Two students choose both No and Yes)
B. Yes. (100%) (100%)

The number of answers was high for telecommunications students, 15 of the 19 students answered the survey. For computers students, the participation was extremely low, only 10 of 39 students. This level of participation is due to the time the survey was delivered. For telecommunications students the course was not finished and some assessment events remain, they continue attending lectures and practices, and the course was *live* and *active*. Computers students were called to answer the survey after the last exam, with final course mark available. This way the course was *dead* and they were focused in the new semester.

Despite the low participation in the survey, author thinks that it is possible to get some findings from it:

Most students think that the puzzle is a good idea, it is an efficient way to learn, and help them to improve soft skills (Q2, Q11, Q13 and Q14).

Regarding the marks, the students think that the way they study the topic doesn't improve significantly the mark they will get (Q11).

Regarding the puzzle tasks, the last three tasks of the puzzle (experts group, puzzle group and the last bulletin of exercises) are similar in usefulness, but the last one is the most useful (Q3, Q4, Q5, Q7, Q8, Q10).

Finally, Q6 show that around half of the students were not satisfied by the explanations of some classmates. However, the overall satisfaction with the experience is high, so misunderstandings were solved before finishing the activity, probably during the resolution of the last set of exercises, where all topics are covered.

Students are also encouraged to write free comments about the activity in the two surveys. Free comments were not very common, but adding all surveys of all experiences there were about 30 comments, most of them positives. Some negative comments were related to the time available to carry out the different activities (4 comments) and the work carried out by the teammates in the puzzle group (one comment). Not as a negative opinion, but more as a concern about missing something important, four students propose different modifications in order to give all students access to all the materials during the activity. This was a common concern that students did not write in the surveys but they asked the teacher when the activity was finished.

Finally, from the point of view of the author, the six experiences were very satisfactory, much better than traditional lectures.

VI. Conclusions

This work presents an experience of learning the binary representation of integer numbers by means of an Aronson's puzzle. The experience was conducted six times during the last three years. Students of telecommunications and computers were involved.

A first satisfaction survey was conducted just at the end of each experience. A second satisfaction survey was conducted when marks about the topic were published. Student's answers to the both surveys show that the experience is satisfactory. Adding this to the same positive feel from the teacher, the first and main conclusion is that this activity should be repeated in future years.

Another important conclusion derived from the six experiences is the need to balance the workload associated to the segments of the puzzle. This way each group of students finishes its tasks in a similar amount of time.

Students did not ask for an explicit, teacher-validated assessment during the activity. They know they will be assessed later, both in formative and summative ways. However, a formative assessment of the all-in-one exercises of each puzzle group would allow the teacher to be sure that all students have had properly worked all the representation schemas and also would be an opportunity to give relevant feedback to the students. This way, in next experiences the teacher will assess the last set of exercises of each group. But this assessment will be prformed out of the classroom and without grades or marks, only with comments.

As a future work, analysis of academic results will be conducted, to know if the use of an Aronson's puzzle improves learning versus traditional lectures. Also, the way to evaluate soft skills will be investigated, to give students feedback about their strengths and weaknesses in cross-curricular competencies.

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