Educational Robotics from high-school to Master of Science

Emanuele Menegatti[1], Michele Moro[1]

[1] Dept. of Information Engineering, Univ. of Padova, Via Gradenigo 6/A-B, I 35131 Padova, Italy, {emg, mike}@dei.unipd.it

Abstract. This paper presents the design of educational robotics activities at Master level based on the experience developed at secondary school level. The used educational approach is the constructionist theory, in which the robot is the sharable object triggering the learning challenge. All educational activities uses the same robot, i.e. the LEGO NXT robot. How this platform and the constructionist approach can be used as a tool for learning advanced concepts of robotics is shown, presenting both a university guidance activity and the introductory laboratory of a Robotics Msc course. The results of a questionnaire provide evaluation criteria to examine the achieved positive effects.

Keywords: educational robotics, LEGO NXT robot, teaching robotics, teaching with robotics.

1 Introduction

Whereas Robotics has long been an established discipline taught at the engineering education levels, it is nowadays used at earlier educational levels as a new didactic tool. This is due to several factors:

- Robotic applications are becoming more common in every day life and refer to very different areas of interest;
- Several not expensive robotic architectures for educational applications are now available;
- Robotics has proved to be an effective learning tool. It is possible to develop experiences addressing technical and/or scientific knowledge and also other types of competences;
- Many development environments able to support teachers even when they do not have a specific robotic competence are also currently available.

The international community in educational robotics is testing educational curricula enhanced with robotics activities spanning the different educational levels: the most complete of these curricula start at kindergarten and stop at the university. In these projects, robotics usually is presented as a general learning tool at the primary and junior secondary level, and as an autonomous scientific discipline at senior secondary and university levels.

The experience of the authors within the TERECop project [1][2][3] showed that it is possible to reduce the discontinuity separating these two visions of robotics. This

Proceedings of SIMPAR 2010 Workshops
Intl. Conf. on SIMULATION, MODELING and PROGRAMMING for AUTONOMOUS ROBOTS
Darmstadt (Germany) November 15-16, 2010
ISBN 978-3-00-032863-3
pp. 639-648

paper shows that the constructionist approach, which has been always concentrating on basic education, is a powerful tool also to support advance education. Concretely, this can foster university students to implement robotics activities based on constructivism/constructionism and educational robotics architectures, but with the great attention and care of the quantitative aspects typical of engineering.

Since many years the European community stimulates the development of IBSE-oriented projects [4] to cope with the current lack of interest for scientific subjects in young people. This is proved year after year by the smaller and smaller number of students which enroll in university to study science and technology subjects. The implementation of IBSE with the help of robotics appears beneficial and effective as it can address different aspects within the senior secondary school curriculum [5].

Again, the purpose of this paper is to present some results of the experience of the authors in offering robotics examples and projects both as a guidance tool for younger students and as laboratory activities for an introductory course of robotics at university level. After a section dedicated to the 'TERECoP lesson' applied specifically for university guidance purposes, the paper presents the homeworks assigned to the students of the course, together with the results of a questionnaire we submitted to the students. Some final remarks conclude the paper.

2 Educational Robotics at high-school: the TERECoP legacy

IBSE (Inquiry Based Science Education) is considered a mainstream in modern science and technology education. It is inspired by the work of famous psychologists like Piaget, Dewey and Vygotsky who influenced also Papert's constructionism. Shortly this approach encourages open constructivist learning through experimental, preferably group, activities. The teacher acts as a tutor offering questions and problems to be addressed and solved by the learners. It is a discovery teaching/learning strategy aimed to convey new knowledge making the students active experimenters looking for not pre-built solutions to problem.

Many factors make still current scholastic teaching rather far from this view, with a traditional transfer of information from teacher to student and with outcomes of an experiment preannounced to, and just confirmed by, students. Teacher's habits, scarce resources for laboratories in the school, some official curricula constraints are some of these factors. Educational robotics is a way to promote IBSE by means of an attractive, multidisciplinary and not so expensive teaching/learning solution.

The TERECoP project has been dedicated to the definition and implementation of a teacher training curriculum aimed to promote the introduction of constructionist educational robotics mainly in secondary school. Such an approach emphasizes the design and building of shareable artifacts as small robots for an effective and rewarding education and for a deeper learning. Moreover it embodies the idea that learning is an active process in which the student builds up new knowledge when stimulated by open problems and led to use tools in a 'low threshold, high ceiling' context.

The implementations of this training curriculum for teachers in different countries, during and after the project, demonstrated that robotics can actually provide a new

Proceedings of SIMPAR 2010 Workshops
Intl. Conf. on SIMULATION, MODELING and PROGRAMMING for AUTONOMOUS ROBOTS
Darmstadt (Germany) November 15-16, 2010
ISBN 978-3-00-032863-3
pp. 639-648

teaching/learning approach through the definition of suitable didactical units where the robot, after a short period during which it acts as a learning object (i.e. it is the focus of the attention of the student), becomes a powerful leaning tool (i.e. the emphasis has shifted to the didactical purposes of the experience as designed by the teacher). What is relevant is the possibility to exploit this approach to cope the current lack of attention for scientific issues secondary students exhibit in and out of the school: this tendency, documented in several European countries [6], results in a decreasing number of students enrolling in scientific disciplines at university. Considering the specific case of engineering, most of the times a lack of competences (or a lack of interest) for mathematics and physics are one of the biggest initial difficulties for the students.

For this reason, during the TERECoP project, we developed some teaching activities with LEGO Mindstorms NXT aimed at high-schools students to stimulate a deeper understanding of topics like mathematics, physics, geometry, mechanics and even natural sciences. These proved to be effective, provided the students can use a robotic architecture which presents a sufficient level of precision, controllability and programmability. A teacher can easily find these qualities in robot kits currently available on the market. LEGO NXT is particularly characterized by a high flexibility, but also the emerging small humanoid architectures are very effective.

During the TERECoP project, LEGO Mindstorms NXT has proved a flexible, not expensive robotic solution which present most of the qualities required for an introductory laboratory. As analyzed during the TERECoP project, some of these qualities are particularly interesting under the engineering point of view:

- servomotors are angle/angular speed controlled through a PID controlling algorithm implemented by the robot firmware: this provides a sufficient motion accuracy even under a certain degree of mechanical load;
- the usual flexibility of a Lego kit is a good ‘viaticum’ for realizing a spread variety of constructions;
- both Lego and other third-party companies offer a wide spectrum of sensors that in terms of precision and reliability covers most of the requirements of didactical experiences;
- the standard I^2C interface permits teachers and students to develop their own sensors for special applications and/or constructions;
- more than one software environment is available (NTX-G, Bricxcc with the NXC language, Java and Lejos, Robot-C, Labview, Urbi, Python, just to cite some of them);
- the autonomy of the robot is guaranteed even in the case of mobile constructions, thanks to the battery operated ‘core’ brick and the possibility to store programs and data in the brick memory.

In the experiences developed during the TERECoP project we exploited all these qualities demonstrating that you can design and test examples of increasing complexity with an accuracy sufficient to make the student apply nontrival algorithms and quantitative approaches.

Fortunately also in Italy several schools adopted more or less technological advanced proposals to enforce IBSE and constructivist learning, with the relevant examples of the Logo language and of Lego Mindstorms. There are documented experiences in schools of any level, starting from the kindergarten to the senior

Proceedings of SIMPAR 2010 Workshops
Intl. Conf. on SIMULATION, MODELING and PROGRAMMING for AUTONOMOUS ROBOTS
Darmstadt (Germany) November 15-16, 2010
ISBN 978-3-00-032863-3
pp. 639-648

secondary. More recently some schools started to participate to robot challenges like Robocup junior [10] where knowledge and abilities are put in comparison. It is easier to find explicit activities in robotics in technical high school where specific competences make it possible for the students to develop control circuits, sensors and actuators, programming environments and solutions.

Our Department is often involved in guidance activities like open days, specific presentations at local secondary schools, distribution of brochures dealing with our courses etc. Sometimes secondary students are invited to participate to mini-stage, typically lasting one day, during which they can visit our laboratories and be informed about research activities and curricula. These opportunities are even more productive if the students can actively participate in some simple experimental activities: this is rather simple to be organized in a robotic laboratory, both because the university teacher can prepare partly ready-made experiences the students can complete and discuss in a constructivist fashion, and because of the spontaneous attractive they show for robotics. Therefore it is easier to guide the discussion towards the relevance of the scientific entry competences and namely the role played by mathematics and geometry as design tools. These activities can be supplemented by subsequent interventions done by their teachers at school, providing other discussion points and motivating experiences.

The authors thought to exploit these activities to organize a guidance initiative based on educational robotics. The initiative involved 4th year classrooms of secondary technical schools; most of the students have had some previous experience with Lego Mindstorms, but programmed the NXT only via the iconic LEGO NXT-G programming environment.

The laboratory activity was divided into two parts: a general illustrative introduction to robotics and to the LEGO NXT and a practical activity with the students. The first part dealt with the main characteristics of the NXT under the hardware and software point of you, in particular with some engineering characterization of the available sensors. Then, it is shown to the students how the textual-oriented C-like programming language NXC is an interesting way to introduce basic programming structures and even some advanced topics, e.g. multitasking.

During the practical activity the students were given an already assembled robot (in the “Tribot” configuration); they were asked to analyze and program simple robot motions, trying to derive and implement the laws of these motions. The robot task was to follow a black tape on the floor. Most students were able to implement the correct robot behaviour in just 4 hours of lab activity starting from no knowledge (or very basic one) of programming. It was the occasion to point out the usefulness of competences normally acquired during the secondary curriculum, for example goniometry, the solution of polynomial and simple differential equations, some physical and mechanical principle.

This experience gave the authors the persuasion, as confirmed by the accompanying secondary teachers, that this was an effective occasion for the students to get some cues useful for guiding their future choice of the university faculty and to have a more concrete idea of how to work in a technical university laboratory. It is important to stress that the educational approach is the same which piloted our TERECoP project as described in the paragraph above. Thus, concluding this section, it could be said that the constructionist approach in its essential is effective also for an engineering laboratory, as proved also by the following section.

3 Robotics Course for Master in Computer Science

Complex robots are often concerned in a robotic research laboratory but working with them is not necessarily suitable for an introductory laboratory. When such a laboratory is accessed by a relevant number of groups of students, you need to design experiments with simpler, fast assembled and, for obvious reasons, less expensive robots; moreover you should use software tools available for several groups of students and a suitable physical space for making robot easily move.

In this section, the homeworks assigned to the students of the “Autonomous Robotics” course in the second year of the Master of Science in “Computer Science” of the Faculty of Engineering are presented. It has to be noted that this is the first and the only robotics course taken by the students during their Msc. The only affine course is the “Artificial Intelligence” course taken by the student in the same semester. The homeworks were designed as constructinist activities starting from our experiences at high-scool and pre-university level described in the section above. The homeworks are designed in an incremental way in which the software and the algorithms the students have to implement to solve the current homework are based on intellectual and software “building blocks” they developed in the solution of the previous homeworks.

The homeworks are presented as open-ended projects. In fact, the students are told what is the minimum goal to be achieved by their robots, but they are also stimulated to be inventive and to go beyond the minimum goal by them-selves. For instance, Homework 5, because it is complex even at Msc level, is left as optional. Students are invited to undertake it only for additional extra points. However, most of the students undertook it, but, as expected, only a few of them were able to completely solve it.

The teachers forced the students to work in groups of three people. In their working life, most of the times engineers have to work in team, especially when dealing with complex projects. The students were asked to experience teamwork, which is different from the single person work they usually experienced in the rest of courses in their MSc. Moreover, important constructivist aspects arise only in teamwork. Teamwork is not always easy to manage, even if working in team enables to solve more complex works, because each member of the team can concentrate in one aspect of the assigned task.

The students were explained in the class with the theoretical aspects of robot locomotion, robot sensing, robot programming, robot vision algorithms, and probabilistic robotics. The aim of the laboratory activities was to have them to study and to deeply understand by them-selves the practical implementation and the details of the theoretical algorithms presented in class.

In the followings, the homeworks assigned to the students are briefly described, highlighting the learning challenge they were defeated with. An ex-post evaluation of this practical activity, obtained through a questionnaire given to the students after they took the examination, is presented in the next section [7][8].

Proceedings of SIMPAR 2010 Workshops
Intl. Conf. on SIMULATION, MODELING and PROGRAMMING for AUTONOMOUS ROBOTS
Darmstadt (Germany) November 15-16, 2010
ISBN 978-3-00-032863-3
pp. 639-648

Homework 1 – Obstacle avoidance

The robot is placed in front of a first obstacle. It has to avoid the obstacle and to move toward a second obstacle. The robot must stop at 3 cm from the second obstacle.
The learning challenge is: to learn to program the robot with NXC programming language, to control the robot motion, and to program a simple robot behaviour triggered by the sonar sensor. The students made experience with the noise of the sensor and with the inaccuracy of the motors.

Homework 2 – Motion Planning

The robot moves on a green carpet with a white grid painted on it creating square cells on the carpet. Some cells are occupied by known obstacles. Other cells can be occupied at robot run time by movable obstacles. The robot starts at a known location and has to reach the known goal position avoiding the occupied cells by an on-line motion planning engine.
The learning challenge is: to have the robot detecting when is moving from one call to the next one, to have the robot correcting its motion to stay in line with the cells, to create an internal representation of the environment map and of the navigation path, to study and implement a motion planning algorithm (just the name of the "wavefront algorithm" was mentioned to the students, but the algorithm it-self was not explained). The students made experience with multi-thread programming in NXC, the implementation of a robot motion control law, and internal representation of knowledge.

Homework 3 - Omnidirectional Range finder

The robot now is equipped with an omnidirectional camera composed of an omnidirectional mirror and a USB camera attached to an external computer. The robot is moving in a maze realized with a green carpet with white lines. The robot has to detect the white lines of the maze in the omnidirectional image and to calculate line profile in a bird-eye view (like a laser range finder would do with a maze made of walls). The image acquisition and image processing software has to be made with OpenCV libraries [11]. Omnidirectional camera calibration has to be made with the Matlab Toolbox OCAM_CALIB by D. Scaramuzza [12].
The learning challenge is: programming with OpenCV, managing Matlab Toolbox, create an image processing algorithm to discriminate between white and green pixels in the image, choose the correct parameters for the developed image processing software. The students made experience with the implementation of an image processing algorithm, the meaning of calibrating a camera, and the noise in images acquired by a camera.

Homework 4 - Scan Matching and Probabilistic Localization

The robot is in the same maze as in Homework 3 and equipped with the same omnidirectional camera. Every time the robot grabs an image and runs the range finder algorithm developed in Homework 3, the robot has to compare the obtained scan with the map of the maze with a scan matching algorithm (explained only at the theoretical level in class). The output of the scan matching algorithm must be, for every point of the maze, the likelihood that the robot grabbed the omnidirectional image from that point. In other words, the scan matching algorithm calculates the likelihood which the robot is in a given point. The student had a theoretic introduction to scan matching and to robot localization algorithms in class. The map representing the maze as a occupancy grid was given to the students. A scientific journal paper of Menegatti et al. [9] about a robot localization system using an omnidirectional camera and a scan matching algorithm was given to the students.

The learing challenge is: to implement a system starting from the information contained in a scientific journal paper, to study in autonomous way the implementation of scan matching algorithms and to implement one of them in Matlab, to understand the difference between sensor model and sensor readings. The students made experience with matching algorithms, concept of likelihood in probabilistic robotics, and the concept of perceptual aliasing.

Homework 5 - Monte Carlo Robot Localization for NXT

(This homework was optional. Only students aiming for extra points have had to take it)

The robot is in the same maze as in Homework 3 and equipped with the same omnidirectional camera. Using the omnidirectional range finder developed in Homework 4, the students have to implement the Monte-Carlo Localization (MCL) Algorithm (a probabilistic algorithm for robot localization) [13]. The aim is to estimate the actual robot position while this moves in the maze using as input the odometry and the omnidirectional range finder. The sensor data have to be processed by the MCL algorithm to manage the perceptual aliasing, caused by the repetitive structure of the maze. To simplify the implementation the MCL algorithm, this has to run off-line in the external PC once all images and odometry data are collected by the robot moving in the maze on a pre-programmed path in a open-loop fashion. The students were given the same paper of the previous homework and they had to implement the second part of the paper [9]. The students have to show the output of their algorithms as plots with:

- the ground-truth path traveled by the robot
- the path estimated by the odometry measurements
- the particles calculated by the MCL algorithm
- the robot positions along the path estimated by the MCL algorithm (by calculating the robot position at each step in which an image was grabbed as average of the positions of the particles of the MCL algorithm)

The learning challenge is: again to implement a system starting from the information contained in a scientific journal paper, to study in autonomous way the implementation of MCL algorithms and to implement one of them in Matlab, to understand the difference between sensor model and motion model. The students

Proceedings of SIMPAR 2010 Workshops
Intl. Conf. on SIMULATION, MODELING and PROGRAMMING for AUTONOMOUS ROBOTS
Darmstadt (Germany) November 15-16, 2010
ISBN 978-3-00-032863-3
pp. 639-648

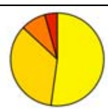
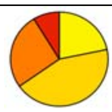
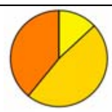
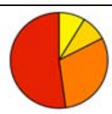
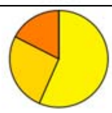
made experience with incorrect estimation from the robot sensors (i.e. the incorrect estimation of the robot position by the odometry data), an algorithm to manage probabilistic believes, and managing of probability in internal representations.

3 Evaluation of didactic impact of constructivist activities

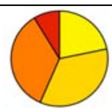
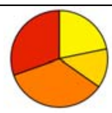
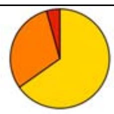
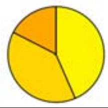
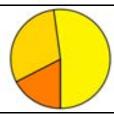
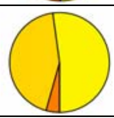
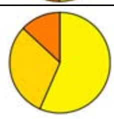
After the last student passed the examination, the teachers asked them to anonymously fill-in the following questionnaire. We wanted to verify if, in the perception of the students, the didactic goals we were aiming to were achieved and if the constructivist/constructionist tools used were perceived as appropriate. The sentences shown in the following table were presented to the students. The student has to assess how much he/she believed the statement was true in his/her experience by choosing among four state: “very much” (light yellow in the plots), “sufficiently” (yellow), “a little”(orange), “not at all” (red). Some of the statements were formulated in negative manner trying to reduce the bias imposed by the x of the statement.

Table 1. Results of questionnaire. Legend:

Very much · Sufficiently · A little · Not at all

1	In the activities of the robotics lab, I used the skills I had learned in other courses only from the theoretical point of view.	
2	Programming the robot allowed me to better understand the arguments presented during the course.	
3	Programming the robot solicited me to deepen the knowledge acquired during the course.	
4	Before the course, I already had all the programming skills necessary for the level of complexity of the developed experiences.	
5	Programming the robot allowed me to improve my 6skills as a software developer.	
6	The fact of working in teams proved useless for my training.	
7	The fact of working in teams was effective for achieving the goals of the experience.	

Proceedings of SIMPAR 2010 Workshops
Intl. Conf. on SIMULATION, MODELING and PROGRAMMING for AUTONOMOUS ROBOTS
Darmstadt (Germany) November 15-16, 2010
ISBN 978-3-00-032863-3
pp. 639-648

8	The fact of working in teams presented some problems in coordinating the work of the group.	
9	The implementation of a project with no upper limit (that is leaving the student to determine how far to go) proved discouraging and difficult to manage (in terms of time and achieved results).	
10	Be assessed on the basis of the final homework was appropriate to check the skills acquired during the course	
11	A robotic experience transfer and/or stimulate the application of trasversal technical-scientific skills (such as mathematics, geometry, physics, electronics, etc.).	
12	Overall the experience was useful for my own growth.	
13	Overall the experience was: useful for the specific examination.	
14	Overall the experience was useful in terms of personal gratification.	
15	Overall the experience was useful in terms of application of acquired knowledge.	

Here some of the results of the questionnaire are highlighted. The teachers wanted the students to have a practical experience for theoretical concepts learned not only in the robotics course, but also in other theoretical courses of their Msc. However, they had not a very positive feedback of this (almost half of the students replied “a little” or “not at all” to Sentence 1), even if this true for the robotics course (only 2-3 people replied negatively to Sentence 2 and 3). Sentence 6 and 7 showed how the teamwork was perceived as important and effective by the students, but Sentence 8 shows that more than half of the students found difficult to work in team. Also the first approach with an open-ended project is difficult: 8 people replied “very much” or “sufficiently” to Sentence 9. However a large majority considered positive the project based experience (Sentences 13, 14, 15) and not only for the sake of the final examination. Finally, it is important to highlight something which bring us back to the basic idea of the TERECop project: a large majority agreed on Sentence 11 and Sentence 3. Showing how a robotics educational tool as the NXT can be motivating (Sentence 3) and not only for the robotics discipline but also for other curricular disciplines (Sentence 11).

Proceedings of SIMPAR 2010 Workshops
Intl. Conf. on SIMULATION, MODELING and PROGRAMMING for AUTONOMOUS ROBOTS
Darmstadt (Germany) November 15-16, 2010
ISBN 978-3-00-032863-3
pp. 639-648

5 Conclusions

This papers shows how the constructivist approach in introducing educational robotics in secondary schools which deeply inspired the TERECoP experience gives important cues on developing effective university activities and on proposing an innovative type of introductory course on Robotics for engineering master students. The risk that the NXT platform could have been felt too childish by our students proved completely unfounded: both the approach and the set of realized homeworks proved fully satisfactory for the students' expectation and for the purposes of the course.

References

1. Alimisis, D.: Designing robotics-enhanced constructivist training for science and technology teachers: the TERECoP Project. In: J. Luca & E. Weippl (Eds.), Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2008, pp. 288-293. Chesapeake, VA (2008)
2. Fava, N., Monfalcon, S., Moro, M., Menegatti, E., Arlegui, J., Pina A.: Teacher training in the Scientific field through Robotics activities: Some experiences form Italy and Spain. In: Proceedings of INTED2009 Conference. 9-11 March 2009, Valencia, Spain (2009)
3. Alimisis, D., Arlegui, J., Fava, N., Frangou, S., Ionita, S., Menegatti, E., Monfalcon, S., Moro, M., Papanikolaou, K., Pina, A.: Introducing robotics to teachers and schools: experiences from the TERECoP project. In: Proceedings of the Constructionism 2010 Conference, 16-20 March 2010, Paris, France (2010)
4. Rocard. M. et al.: Science Education now: a renewed pedagogy for the future of Europe, EUR22845, ISBN – 978-92-79-05659-8, European Communities, Brussels (2007)
5. Arlegui, J., Demo, G.B., Moro, M., Pina, A.: Discussing about IBSE, Constructivism and Robotics in (and out of the) Schools. In: Proceedings of the Constructionism 2010 Conference, 16-20 March 2010, Paris, France (2010)
6. Sjøberg, S., Schreiner, C.: The ROSE project. An overview and key findings. http://folk.uio.no/sveinsj/ROSE-overview_Sjoberg_Schreiner_2010.pdf (revised version of an invited expert input to the Eurydice comparative study on Science and Mathematics education) (2010)
7. Drew, J., Esposito, M., Perakslis, C.: Utilization of Robotics in Higher Education. In: EDSIG Information Systems Education Journal, vol. 4, n. 2, Chicago, IL (2006)
8. Mavridis, N., Rashdi, A., Ketbi, M., Ketbi, M., Marar, A.: Exploring Behaviors & Collaborative Mapping through Mindstorms Robots: A case study in applied constructionism at senior-project level. In: Proc. of the Innovations in Information Technology Int. Conf. IIT '09, 15-17 December 2009, pp. 305-309, AI-Ain, United Arab Emirates (2009)
9. Menegatti, E., Pretto, A., Scarpa, A., Pagello E.: Omnidirectional vision scan matching for robot localization in dynamic environments. In: IEEE Transactions on Robotics Vol: 22, Iss: 3 ISSN: 1552-3098, June 2006, pages 523- 535 (2006)
10. Robocup Junior Italia, http://www.robocupjr.it/
11. OpenCV (Open Source **C**omputer **V**ision) http://opencv.willowgarage.com/wiki/
12. D. Scaramuzza, Omnidirectional Camera and Calibration Toolbox for Matlab (http://robotics.ethz.ch/~scaramuzza/Davide_Scaramuzza.htm)
13. Thrun, S., Burgard, W., Fox, D.: Probabilistic Robotics, MIT Press, Cambridge, MA (2005).

Proceedings of SIMPAR 2010 Workshops
Intl. Conf. on SIMULATION, MODELING and PROGRAMMING for AUTONOMOUS ROBOTS
Darmstadt (Germany) November 15-16, 2010
ISBN 978-3-00-032863-3
pp. 639-648