Design and Implementation of a Biologically Inspired
Swimming Robot

Final Report - June 2014

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- Ana Barata for helping us to translate and distribute our survey.

ABSTRACT

This report presents the development of a fish-like robot, intended to be an educational toy teaching about mechanics, programming and the physics of floating objects. Trying to face an arising global energy shortage and sustainability problems of oceans, children´s interest for technology, especially biomimetic approaches, has to be awakened. The main focus of this project was to create a robot with controllable swimming directions and the opportunity to customize parts and thus experiment on physics of floating objects. Therefore, the locomotion principles of fishes and mechanisms developed in related projects were analysed. With this background knowledge a prototype was designed and implemented. The main achievement is a new tail mechanism to propel the robot. The tail resembles the undulation motion of fishes´ bodies and is actuated in an innovative way. First experimental tests revealed the potential of the proposed method to effectively generate forward propulsion.

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GLOSSARY

BCF	Body and/or caudal fin
CPU	Central processing unit
DC	Direct current
DOF	Degree of freedom
EPS	European project semester
GPS	Global positioning system
IC	Integrated circuit
I/O	Input/output
IPMC	Ionic polymer metal composite
ISEP	Instituto Superior de Engenharia do Porto
MHz	Mega Hertz
MPF	Median and/or paired fins
PWM	Pulse-width modulation
RAM	Random access memory
RISC	Reduced instruction set computing
ROM	Read-only memory
SRAM	Static random access memory
USD	United states dollar
V	Volt

1. INTRODUCTION

1.1 Presentation

We are an international team of four members, presented in detail in Table 1. We take part in the European Project Semester (EPS) 2013/2014 at Instituto Superior de Engenharia do Porto (ISEP) that started in the end of February 2014 and lasted for four months. During the EPS program we worked on the project “Biologically Inspired Swimming Robot” that will be presented in this report. Additional classes about Teambuilding, Project Management, and Communication as well as about Marketing, Sustainability and Ethics & Deontology serviced the progress of the main project.

Table 1: Presentation of team members[1]

ALICIA MORENO ISHII	MAGDALENA HEIBECK	MARCIN BLAZEJEWSKI	RASMUS GABRIEL NYBJÖRK
			
Building Engineer	Naval Architecture and Maritime Engineering	Mechanical Engineering and Computer Science	Electrical Engineering
Spain	Germany	Poland	Finland

1.2 Motivation

Out of 14 project proposals our team chose to design, develop and implement a swimming robot that is biologically inspired. Our motivation is based on multiple reasons:

1. Oceans are of great importance to us. They cover 70% of the earth´s surface and contain 99% of its living space [**1**]. We are convinced that any research done in the aquatic field may help preserve biodiversity, find and use natural resources more sustainably, improve means of transport, understand climate and weather, and finally improve our economy.

[1] All tables and figures are original if not stated differently.

2. In addition, we like the biomimetic approach of the task. Nature provides a database of solutions that - due to selective pressure - ensure a high degree of efficiency. In our case it was discovered that the appealing nature of fish movement involves higher efficiency and a more remarkable maneuverability compared to manmade vehicles propelled by thrusters [**2**]. That is why we want to try to discover the principles behind that, mimic them and apply them to manmade craft.

3. Lastly, we are intrigued by the general idea of creating a moving robot and assessing our approaches through functional tests and professional feedback.

1.3 Problem

The world´s oceans are threatened by sustainability problems due to humans´ actions [**3**]. On the other hand, humans strive for technological advancement, often with the target of maximizing profits. That is why today´s robots are not only useful for industry to perform repetitive processes, but also have meanwhile gained a high level of intelligence, which makes more applications possible. Regarding the aquatic field, they can, for example, perform tasks of inspection, maintenance and repairing in areas not possible or too dangerous for humans to access [**4**]. Despite all that, the sustainability problems of the oceans have not been met yet, and our impression is that public awareness about that fact is low.

In addition to the critical ocean issues, the arousing global energy shortage [**5**] has to be faced. To be able to maintain today´s standards of living, research on improving the energy efficiency of technical devices is indispensable.

The solving of the problems stated above also depends on the competences and motivation of future generations. People are needed who produce smarter ideas and technologies while obtaining profitability at the same time. To make that happen, children need to receive good education. Essential factors in that are enjoyment and engagement, which is why playful learning activities become increasingly important [**6**].

1.4 Objectives

Our aim is to provide an innovative and engaging opportunity for children to learn. If children achieve a high level of expertise while maturing to be a professional, they will hopefully be able to perform future progress in technology development. To arouse children´s curiosity and enthusiasm for technology, we want to provide the opportunity to experiment with laws of nature and state of the art technologies rather than having them spend more time in classrooms receiving education in a traditional way. We want to develop a toy for children, which is a *construction kit for a swimming robot with biomimetic features*. By self-assembling the product and being able to program and change certain features, the user naturally learns about robotics and the physics of floating objects.

Also, we can draw attention to critical ocean issues by providing additional information along with the toy. Like this, we hope to awaken consciousness for existing sustainability problems and contribute to solve them.

For the scope of this project we have scheduled the design and implementation of a prototype that is able to perform basic features of the future product, as listed in the following subsection. At the same time, the team has to always bear in mind the marketability of the final product, sustainability issues as well as ethical and deontological concerns.

1.5 Requirements

The developed prototype of the biologically inspired swimming robot is aimed to incorporate the following features:

- Waterproof body
- Generation of forward propulsion
- Steering in the horizontal level
- Submersion underwater and controllable swimming depth

In addition, an opportunity shall be integrated to modify specific physical parameters of the swimming robot to comply with the final idea of a toy that children can conduct physical experiments on. Alterable features can be the fins´ shape, size and motion pattern, as well as the amount and distribution of masses.

Furthermore, in the project proposal a 12 hour-power autonomy is required.

1.6 Functional Tests

A series of tests is required to make sure that the newly designed and implemented biologically inspired swimming robot is working correctly, fulfilling the requirements stated above. The first test stage is conducted in dry conditions and examines the actuation and controllability of the robot´s propulsors:

- Test if tail mechanism is able to generate an undulating motion
- Test if servomotor actuated fins oscillate in required rotation angles

The second test stage takes place in the water and includes the following tests:

- Test if the robot´s body is waterproof
- Test of the robot´s immersion to detect the amount of ballast weights required
- Test of propulsive forces generated by tail mechanism
- Test of steering left/right
- Test of submersion and controlling swimming depth

The execution of these tests and their results are described in Subsection 7.5.

1.7 Project Planning

To be able to finish the project successfully in the available time and with the available resources, the project had to be managed deliberately. A detailed project management planning will be presented in Chapter 3. At this point, only two major project specifications are displayed, which are the Gantt-Chart and task allocation.

The Gantt-Chart (Figure 1) lists the required work assignments and their duration. It provides a general overview of the available time and helps the team to assess the work´s progress.

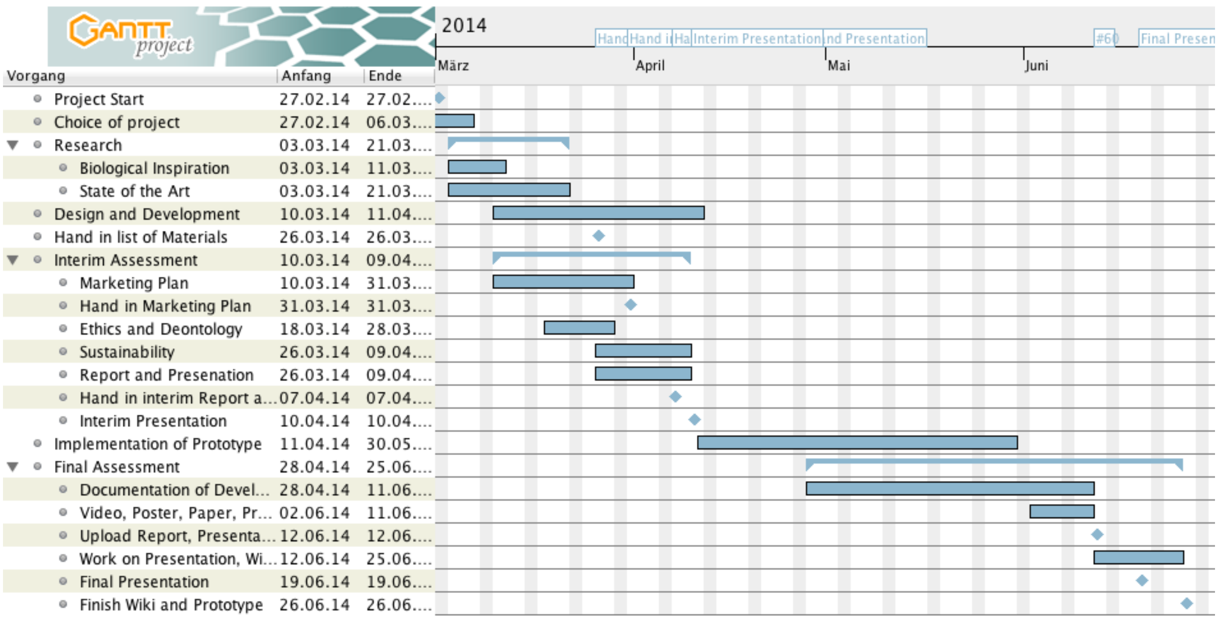


Figure 1: Gantt chart

Table 2 presents the allocation of main tasks among the team members.

Table 2: Task allocation

TASK	RESPONSIBLE TEAM MEMBER
Research on Existing Robotic Fish	All (Magda)
Development of Robot´s Mechanical Architecture	Marcin, Magda
Mechanical Details	Marcin
Electronics	Rasmus
Project Management	All
Marketing Plan	Alicia
Sustainability	Alicia, Rasmus
Ethics and Deontology	Magda
Interim Presentation	Alicia, Magda
Final Presentation	Alicia, Magda
Paper	Magda
Leaflet	Alicia
Video	Rasmus
Poster	Alicia

1.8 Report Structure

The report begins by assessing studies about the locomotion of fish, related scientific projects, toys in the market and components considered. Following that, Chapter 3 addresses the project management tools applied to this project. The suggested marketing concept is presented in Chapter 4 and eco-efficiency measures for sustainability discussed in Chapter 5, whereas Chapter 6 approaches ethical and deontological concerns. Based on that groundwork, the developed architecture and components used are introduced in Chapter 7. This chapter also covers the implementation process and experimental evaluation of the prototype. Finally, Chapter 8 concludes this report, discussing the main results obtained and presenting ideas for future developments.

2. STATE OF THE ART

2.1 Introduction

To develop a swimming robot with biomimetic features that can be used as a toy in the future, extensive background knowledge has to be gathered. The goal is to collect ideas for structures and components and thus lay foundations for a product development and marketing, which successfully complies with the initially set requirements (1.5).

Therefore, we have seen through a large collection of scientific papers and books on related research works to find inspiration and avail already learned lessons. Also, we analysed the products on webpages of several suppliers, searching for possibly suitable components and finished products.

This chapter will provide information about the results of studies about locomotion of fishes and, afterwards, present already developed related projects. Special focus will be placed on existing methods to control a robot´s swimming depth and waterproofing techniques. Furthermore, educational toys on the market will be presented in order to assess available features and educational values. An examination of motors, control units, motor shields, batteries and an outside control is aimed to assist the future selection of suitable components for the robot. Finally, a conclusion will be drawn from all information gathered.

2.2 Biological Background Knowledge

The product, which is developed in this project, is supposed to have biomimetic features. From the entire field of aquatic locomotion, which describes the biologically propelled motion through a liquid medium [**7**], the team chose to mainly seek inspiration in the body architecture and motion patterns of fishes. In order to mimic them, they first had to be examined thoroughly.

Fishes are generally vertebrate aquatic animals with a slender skeleton. Their locomotion is ensured through muscular contractions that propagate along the entire body and fins. This way, they perform undulating (wave-like) and oscillating movements [**8**]. The different fins of fishes are displayed and labelled in Figure 2 [**9**].

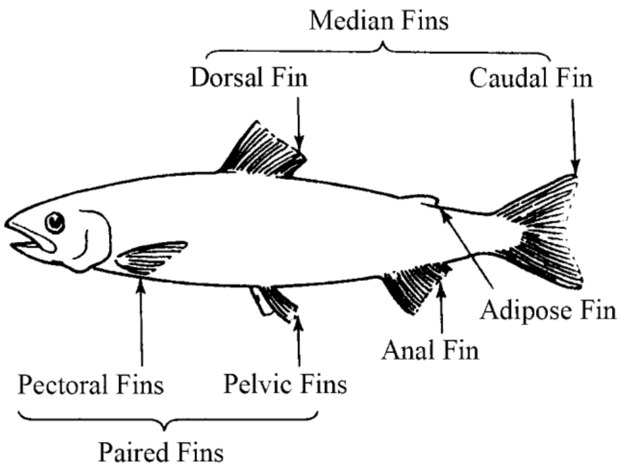


Figure 2: Definition of terms: fishes´ fins

Fishes use their fins and/or entire bodies in order to perform three basic swimming functions: cruising, accelerating and maneuvering (including station-keeping). Depending on which parts of the body contribute to achieve these functions, it is distinguished between two styles of aquatic locomotion: fish swim either by body and/or caudal fin (BCF) movements or using median and/or paired fin (MPF) propulsion [**10**]. The BCF propulsion can achieve great thrust and accelerations, while MPF movements are employed at slow speeds, enabling maneuvering with high agility and better propulsive efficiency [**11**].

A state of weightlessness (neutral buoyancy) allows fishes to stay at a particular water depth. To achieve this state, various ways have evolved among fishes: the entire fish´s density can be decreased approaching the one of water by reducing the amount of heavy tissues and incorporating more spaces filled with low-density compounds (e.g. lipids) or gas in the swimbladder. In addition, fish´s fins and body surfaces can generate lift during forward movement, if they have an appropriate shape and angle of attack, and thus control the swimming depth [**9**].

2.3 Related Projects: Fish-like Robots

Because of their excellent swimming performance, fishes have already received considerable attention from engineers: biologically inspired robots have become an active research field and prototypes with different propulsive mechanisms have been developed. Evaluating these approaches is aimed to serve as groundwork for picking and combining existing ideas and developing a swimming robot that incorporates many functions while obtaining little complexity.

The team´s advisor Manuel Silva, who was involved in the development of a previous fish-like robot at ISEP, handed on a large collection of related scientific papers. This section provides an overview of the evaluation results and focuses especially on the previously developed prototype at ISEP and different propulsive mechanisms.

*2.3.1 Existing Prototype at ISEP [**12**]*

In 2013, José Augusto M. Silva, a student at the Department of Electrotechnical Engineering at ISEP, developed a fish-like robot. Generally, a lot of conclusions can be drawn from the implementation and testing of a prototype. That is why in this section the realised project, its achievements and problems will be presented in order to avail the already learned lessons.

The research focussed on examining the difficulties in developing this type of vehicles and pointing out the most important aspects for effective and efficient aquatic locomotion. The existing prototype is considered to be the first in a series of biological inspired swimming robots with the final purpose of being used for inspections.

The robot consists of an acrylic tube, a spherical cap at its front, a caudal fin at its end, and two pectoral fins at its "chest" (Figure 3a). The pectoral fins propel the robot and the caudal fin contributes to steering in the horizontal level (MPF propulsion). The three fins are actuated by one servomotor each. A compass is used to control the robot´s heading. It directly communicates with the control board (an Arduino platform). An RF module allows wireless communication with the robot, enabling its control. Two lead batteries are used to separately supply the servomotors and the other equipment with power, allowing power autonomy of around two and a half hours.

The robot is 415 mm long, 125 mm wide, 180 mm high and 2.8 kg heavy. Due to the small body weight/volume ratio the robot floats on the water surface and is not able to submerge.

Throughout the testing of the prototype some problems had to be coped with. First of all, the robot was not entirely tight: some water leaked into the hull near the roller bearing that supports the pectoral fin´s shaft. Adding a new *retainer* (tight ring made of rubber) at its front eliminated the leakage. Also the *bellow*, which isolates the mechanism to actuate the tail fin, had to be sealed with glue, subsequently. Furthermore, stability problems were detected in the first tests. To prevent the robot from rotating around its longitudinal axis, more weight had to be added at the robot´s bottom. Lastly, the compass´ functionality was disturbed by the presence of ferromagnetic materials in the environment. No acceptable solution could be found using the available components.

From hydrodynamic tests performed with the prototype the following conclusions were drawn: changing the position of pectoral fins is enough to allow or prevent locomotion of the robot. The different pectoral fin models displayed in Figure 3b were tested and the one in the middle found out to be the most effective.

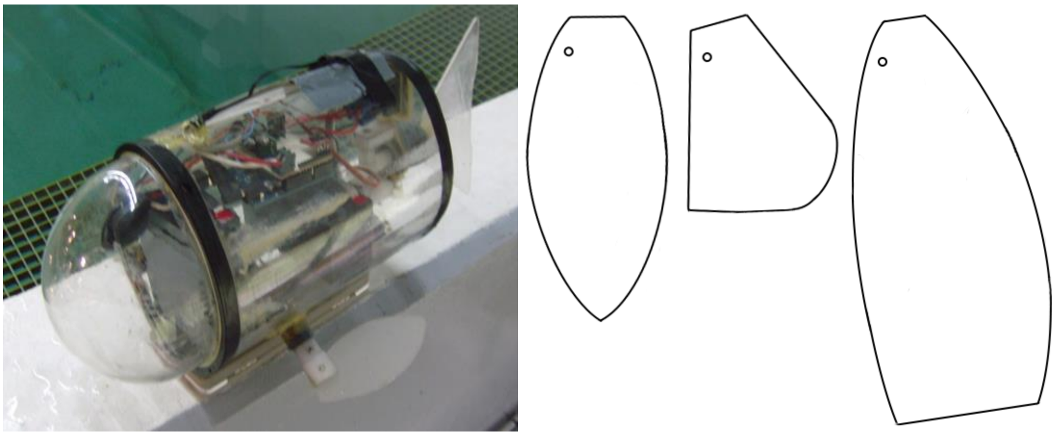


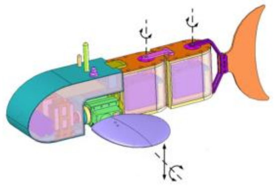
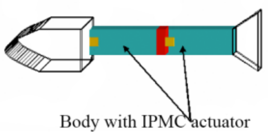
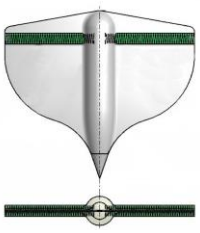
Figure 3: (a) Existing prototype; (b) tested pectoral fins

In the project´s outlook it was recommended to add two or even four, symmetrically arranged pectoral fins to the robot to increase the propulsive forces. It was proposed to solve the problems with the compass by using a linked correction system and global positioning system (GPS). Also, it was suggested to increase autonomy by using solar panels. Finally, the idea was introduced to improve the robot´s locomotion by developing an articulated body, more similar to the one of real fish. The implementation of a depth control could enable the robot to submerge.

2.3.2 Comparison of Approaches for propulsive Mechanisms

Around the world, there have been developed several approaches for biomimetic robots in the maritime field. Table 3 presents principal examples for state-of-the-art developments and compares them by application areas and mechanical structures.

Table 3: Mechanical structure of existing fish-like robots

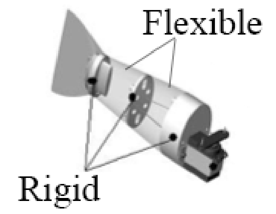
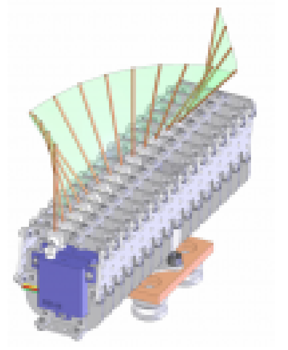
PICTURE/SKETCH	INTENDED APPLICATION	MECHANICAL ARCHITECTURE	BODY ACTUATION	
	Inspection purposes (existing prototype at ISEP)	MPF propulsion; Two pectoral fins for propulsion, one back fin for steering	3 servo motors	[12]
	Neural-based Control of Modular Robotic Fish with Multiple Propulsors	BCF propulsion; 2 pectoral fins with 2 degrees of freedom, 2 moving tail segments	6 servo motors	[13]
	Swim, walk, maintain station, crawl at bottom of sea, 5 controllable degrees of freedom (DOF)	6 paddles/flippers at sides of cuboid body provide thrust and control	6 motors	[14]
	Microrobot that can swim smoothly in aquatic medium, application in medical field and industry	BCF propulsion; Body with IPMC (ionic polymer metal composite) actuator	IPMC generates large bending motions under low driving voltage	[15]
	Realizing smooth motion like manta with soft body	Rubber body (manta shape), two bending pneumatic rubber actuators with two DOF in front of the fins	Bending Pneumatic Rubber Actuator	[16]

The presented fish-like robots have different biomimetic approaches. The existing prototype at ISEP requires a small amount of motors and can perform basic translational movement at the water surface. The next two approaches are based on a more complex interaction of moving segments and are able to operate under water. Especially the second robot presented copies the movement of fish, such as a shark, with high accuracy. The robot maneuvers through an undulating movement of the tail segments and pectoral fins that can be pitched around two axes.

The last two presented robots are not actuated by motors but by pneumatic or IPMC solutions. These mechanisms enable them to perform a smoother, more natural motion. Nevertheless, it was already decided at an early stage of the project, that only *traditional motors* would be used to actuate the robotic fish´s body that is to be developed. Motors are commonly used actuators with a wide range of applications, which is why, in our opinion, children should have the chance to experiment with them.

Trying to find a mechanism that enables also a motor-actuated body to perform a smoother motion and more precise maneuvering, more research was done on single mechanical features of robotic fish. The results are displayed in Table 4.

Table 4: Existing mechanisms (motor-actuated) that improve biomimetic features

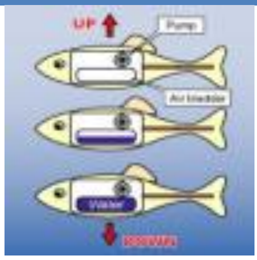
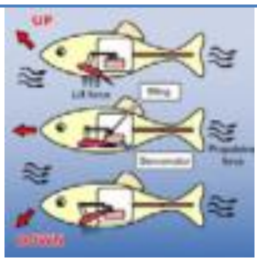
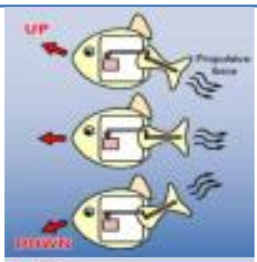
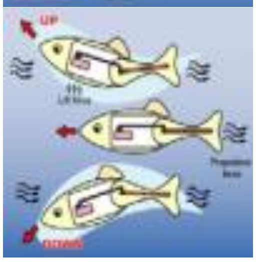
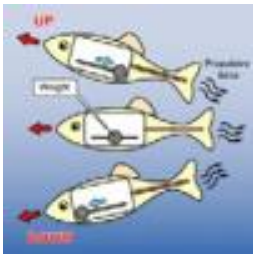
PICTURE/SKETCH	FUNCTION	MECHANICAL ARCHITECTURE	BODY ACTUATION	
	Smooth motion of back fin	Back fin consists of 3 rigid pieces with flexible parts in between	1 servo motor	[**17**]
	High degree of maneuverability, rapid accelerations and effective station-keeping	Stiff rays connected to actuator, flexible membrane in between	1 servo motor per ray	[**18**]

Whereas the second approach is characterized by the application of many motors and a complex controllability, the first idea of combining flexible and rigid parts in a fin actuated by one motor only, seems more feasible.

2.4 Methods for Ascending and Descending

One of the project´s major targets is to make the robotic fish submerge under water and enable steering in a vertical level (1.5).Table 5 sums up the existing methods for ascending and descending a floating object [**19**].

Table 5: Mechanisms for steering in the vertical level

SKETCH	DESCRIPTION	ADVANTAGES	DISADVANTAGES
	Pump/piston changes water amount in tank (altered relation between buoyancy and gravitation)	Diving depth of the robot fish can be controlled accurately	Slow response, space consumption of tank/piston, source of air required for ascending
	Attack angle of pectoral fins is changed	Quick response and high dynamic performance	Minimum swimming speed required to utilize lift force of fins
 	Tail rotates around transverse axis, generated momentum rotates the robot; Body bends to certain shape, up- and down-motion through lift forces	Quick response and high dynamic performance	Minimum swimming speed required to utilize lift force of fins, more fragmented body architecture
	A moving inside weight changes fish´s barycentre, thus the direction is pitched	Mechanism is set inside of body, thus the mechanism´s motion isn't affected by water flow	Space consumption inside body, questioned effectiveness (relation of moving inside weight to overall mass)

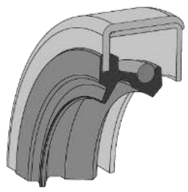
The comparison reveals that there exist several different methods varying in technical complexity and effectiveness. The selection of a suitable mechanism for the developed robot will be dependent on its feasibility and the available space inside the body.

2.5 Waterproofing

The swimming robot is projected to operate underwater. To prevent any contact between the delicate electrical devices and the surrounding water, it is crucial to seal all shell openings reliably. The expected critical areas are *shaft openings*, where shafts pass through the shell, and *detachable connections* in between shell segments, which are necessary for the robot´s assembly and later works on its insides.

In order to find suitable sealing mechanisms, the solutions proposed in model-making forums concerned with underwater vehicles (for example the German webpage “roboternetz.de” [**20**]) were evaluated. As a result, the attention was drawn to products of the German company “Freudenberg Sealing Technologies” [**21**]. The globally operating company offers a wide range of sealing solutions, which is why it is a useful source of ideas for this project. The mechanisms that seem applicable to the swimming robot are presented in Table 6.

Table 6: Possible sealing solutions

Sealing Solution	Functionality	Advantages	Disadvantages
Bellow [22] 	Flexible tube (folded like accordion) surrounds the shaft; Adjacent components are sockets (sealable through tight connection)	-Big size range -Inexpensive -Protects against contamination and physical impacts	-Allows limited rotation angle -Interfaces with sockets need to be sealed
Radial Shaft Seal [23] 	Sealing lip (elastomer) has point contact with shaft; Spring increases contact pressure; Minimum diameter of shaft: 3 mm	-Allows unlimited rotation angle -Protects against contamination	-Requires high accuracy of shaft´s surface
O-Ring [24] 	Elastomer loop is placed in a groove and compressed by adjacent parts during assembly (point contact)	-Big size range -Inexpensive -High resistance against pressure, temperature, chemicals and physical stress	(For dynamic application:) requires high accuracy of shaft´s surface
Shaft inside lubricated Socket	Shaft is led through socket with slightly larger diameter (specific overlapping length is required); Grease inserted in the gap seals of water due to its hydrophobic character	-Inexpensive -Easy to implement oneself -Functions also as bearing against rotation around the transverse axis	-High effort for maintenance (renew lubrication) -Space for overlapping and high accuracy required

2.6 Existing Educational Toys

This project initiates the development of an educational toy. The final product is aimed to be a construction kit, that not only teaches about mechanics but also programming and the physics of floating objects. In order to be able to place a successful toy on the market, existing products have to be studied carefully, at first.

Currently, there is a wide range of toys available in the toy's market. Three types of toys are presented in this section: Construction and Building Sets, Robotic Toys and High Tech Toys. These three types are directly associated with all the aspects that involve the main features of our future toy. The fourth one, Related Toys in Aquatic Field, is crucial to understand which are our possible opportunities and strengths.

2.6.1 Construction and Building Sets

A Construction and Building Set is a collection of separate pieces that can be joined together to create models. The products can be used as toys once are completely assembled or can been taken apart again to build another structure. There are different types of Construction and Building Sets. Some of them have a predefined structure that kids have to achieve. Others have a wide range of pieces, enabling children to build their own structures. Finally, there are sets that combine both of these features: With the same pieces kids can either make their own or predefined constructions.

In Table 7, the principal Construction and Building Sets that involve our product are presented, evaluating their features and their educational value.

Table 7: Construction and building sets

CONSTRUCTION AND BUILDING SET	FEATURES	EDUCATIONAL VALUE
LEGO BRICKS [25] 	- Plastic bricks with a wide range of colours and dimensions - The pieces are easy to assemble together but the joints are strong enough to construct structures - Possibility of create predefined structures and also create new ones	- Understand physics - Develop the creativity - Basics of structural engineering - Develop the visual-spatial skills
K'NEX BUILDING SETS [26] 	- Interlocking plastic rods, connectors, gears, wheels, and other components - Easy to make large models - It is possible to create mobile structures without special pieces - Certain pieces are flexible	- Same as LEGO - Great educational value in construction structures. Possibly to create trusses[2].
MECCANO MULTIMODELS [27] 	- The pieces are made of metal and plastic - The joints are held with nuts and bolts - Mainly for modelling machines	- Understand mechanical structures - Learn to read engineering drawings - Develop the visual-spatial skills

Each product that is presented has different kinds of pieces to build structures. The LEGO Bricks and the K'NEX Building Sets are more focussed on the construction and structural knowledge, and the MECCANO Multimodels in the mechanical understanding.

2.6.2 Robotic Toys

The Robotic Toys are not made for utilitarian use. They are relatively cheap and mass-produced. The Robotic Toys have different skills like mechanical and interactive features. In the market there are a lot of Educational Robots available that teach about several subjects and have lots of features, as displayed in the Table 8.

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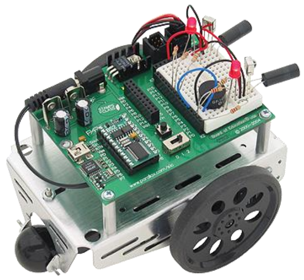
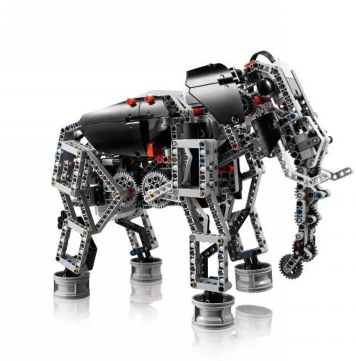
[2] Truss: A framework, typically consisting of rafters, posts, and struts, usually for supporting a roof, bridge, or other structure [**76**].

Table 8: Robotic toys

ROBOTIC TOYS	FEATURES	EDUCATIONAL VALUE
6 IN 1 EDUCATIONAL SOLAR KIT [28] 	- Six different models can be constructed including an airboat, windmill, puppy, and two different planes. - No requires battery, has a solar panel - Contain a 1.2V DC motor	- Understand the benefits of solar energy - Understand the process of take energy from the sun and transform it to generate electricity - Learn physics
PARALLAXBOE-BOT ROBOT KIT [29] 	- Re-programmable robot kit - Contain infrared sensors - Has two microcontroller - Parallax continuous rotation servos for the drive wheels	- Learn to use motion programs and programming language - Learn build simple circuits - Understand basics of programming
LEGO MINDSTORMS [30] 	- The main component is the NXT Intelligent Brick that control the sensors and the motors - Contain tree Servo Motors - Have four sensors: ultrasonic sensor, colour sensor and two touch sensors. - Remote controlled	- Understand basics of programming and programming language - Learn about mechanics - Explore the application of technology - Learn how robots use feedback from sensors - Program and use the remote control

In the world of the Robotic Toys, there are available simple robots like the 6 in 1 Educational Solar Kit that only need a DC motor and also very complex robots like the line up of LEGO Mindstorms that have different motors and sensors. Of course, there are also more complex Robotic Toys in the market, but they are not inside of our ambit of study.

2.6.3 High Tech Toys

The High Tech Toys, also called Smart Toys, are the new trend in the World of Toys. The world is becoming highly technological and digitalized and most of the aspects of the Europeans life are growing dependent on computers and modern-day gadgets [**31**]. It is for this reason that sales in this kind of toys are growing faster. A robot can be also a High Tech Toy, but in this case, the newest products that have revolutionized the Toy's market are presented in Table 9.

Table 9: High tech toys

HIGH TECH TOYS	FEATURES	EDUCATIONAL VALUE
SPHERO 2.0 [32] 	- Smartphone-controlled toy - Rolls at speed of 2m/s - There are educational apps available to learn while the kids are playing with the toy - Can be use with other Sphero 2.0 like a social game	- Learn basic concepts of programming - Learn physics
ANKI DRIVE [33] 	- New concept of remote-controlled car - Has a complex system that can localize where is the car and the position of other cars - Has a tinny camera under - Every car has a track mat - Smartphone-controlled toy	- Lean basics of physics
LITTLEBITS [34] 	- Modular electronics that snap together to create circuits - Makes electronics look attractive and easy to kids - Every module has a specific function like motors and sensors.	- High educational value in different levels of programming - Learn electronics - How to make circuits

LittleBits toy has a high educational value in programming and electronics. Spero 2.0 and Anki Drive also teach physics and programming, but are more dynamic and interactive toys which is presumably more attractive for kids.

2.6.4 Related Toys in Aquatic Field

It is necessary to study the available Aquatic Toys in the market. There is no wide product range available and it is hard to find an Aquatic Toy that has any educational value. Table 10 shows tree toys that have different complexity and features. The educational value it is not covered in two of them, but it is important to study these toys because they have interesting features that can be useful for the swimming robot developed in this project.

Table 10: Related toys in aquatic field

TOYS IN AQUATIC FIELD	FEATURES	EDUCATIONAL VALUE
ROBO FISH [35] 	- Can swim and dive in the water - Produces a realistic swimming motion - Can swim in five different directions: forwards, up, down, left and right - Uses two 1.5V A76 or LR44 size alkaline batteries	- Does not have educational value
TAMIYAMECHANICALBLOWFISH [36] 	- Construction Kit - Propelled forward by a left-right moving tail fin rotated by a crank and link rod - Includes Type 130 motor with low gear ratio (58.2:1) for controlled propulsion - Only can swim in the surface	- Learn about mechanic - Physics in water
ZIPHIUS [37] 	- It is an app controlled aquatic drone - The skilled HD camera allows a 160º tilting angle - Only can swim in the surface - Autonomous behaviour also	- Does not have educational value

The most important feature of the Robo Fish Toy is that it can swim and dive in the water but it is not an educational toy. Ziphius has a high complexity and quality, but also, it does not have any educational value. The Mechanical Blowfish is a self-assembly construction kit that can teach physic and mechanic. But once the toy is completely assembled, there is nothing that the user can change or experiment with.

To sum it up, there is no toy available in the market that can swim under water and has a high educational value.

2.7 Motors

2.7.1 DC Motors

Direct current (DC) motors are electric motors, which rely on magnetic repelling and attraction between magnetic fields. Coil of wire inside the motor with current running through it produces on electromagnetic field that being pulled and pushed creates torque, which rotates the motor.

In our project we use a 6 Volt (V) DC motor to provide a steady and easily controlled movement of the fin responsible for the robot propulsion in water. We had to consider different ways of motion translation between one-way rotation of the motor and the "flapping" movement of the fin. The detailed description of the developed mechanisms is provided in the project development chapter (7.2.1).

Gears in DC motors allow the change of rotation speed and torque of the rotating shaft, using the same input motor. This gave us the possibility to choose from a range of small, low cost 6V motors (Figure 4).

Figure 4: DC motor

Considered motors are displayed in the following Table 11:

Table 11: Comparison of 6 V DC motors

MODEL	GEAR RATIO	TORQUE [KG-CM]	ROTATIONS PER MINUTE	FREE RUN CURRENT [MA]
POL-993	30:1	0.3	440	40
POL-998	50:1	1.1	625	100
POL-1101	100:1	2.2	320	80
POL-995	250:1	4.3	120	70
POL-994	**298:1**	**5**	**100**	**70**

All compared motors are available in InMotion store, with the same price of 14.95 € and exactly the same size of 24 x 10 x 12 mm. Our choice was the motor with model number POL-994, marked in bold in Table 11. We have chosen this motor because our propulsion fin will require a lot of torque but not so fast rotational speed. One rotation of the shaft will give us one full "flap" of the fin. The motor is compatible with Arduino control board, which is the control unit we will use in our robot.

2.7.2 Servomotors

A servomotor is part of a servo system. A servomotor has a very precise position feedback, it can tell a responsible supervisory control exactly where the motor shaft is located. Along with servo drives, the servo motor used to run very accurately, for example, always holds a certain speed whether driving up or down a hill, or to always stay at a certain place with centimeter, millimeter - or micrometer precision, depending on application. Of course, provided that the resistance to movement does not exceed the design capacity. A typical application of servo motors are two bands that have to go in exactly the same speed when you connect your two servo drivers and allows one to follow the other as a slave [**38**].

In our project we need three servomotors that operate on 6 V and the range of rotation is not required to be more than 180 °. Also, high speed and big torque are advantages because underwater movement is heavy operated, but we also had to consider not to require too high currents in order to ensure longer lasting power autonomy.

Table 12: Comparison of 6 V servo motors

MODEL	RANGE OF ROTATION	TORQUE [KG-CM]	MAX. SPEED AT RATED VOLTAGE (°/S)	RATED CURRENT [MA]
HITEC HS-422	180	3.0	286	130
HD- 1160A	180	2.7	165	180
AR-3606HB	360	6.7	165	300

AR-3606HB needs quitea lot of current because it hasa high torque and it has too large dimensions for our purpose. The servomotor Hitec HS-422 fits our purposes the best because it uses less current than HD-1160A but generates higher torque and is quick rotation.

2.8 Control Unit

A microcontroller (integrated circuit, chipset, etc.) is a small computer with Central Processing Unit(CPU), Random Access Memory(RAM) and program memory integrated completed with support functions (clock generator, watchdog, etc.) and different types of Input/output (I/O) devices (such as conversion of analog signals) on a single silicon chip called integrated circuit (IC) [**39**].

These circuits are optimized to operate and work together with other electronic components, and the most common application is embedded systems. They represent by far the most common type of microprocessor units in terms of numbers sold circuits.

Microcontrollers are available in many performance classes and with varying word length (4, 8, 16, 24, 32 bits, etc.) but the division is far from rigorous. The simplest 4-bit circuits are used for simpler rules and control systems, and 8-bit systems can be found in many consumer products. The more powerful 16 - and 32-bit circuits often have performance approaching that of modern personal computers and are used in broadband routers, mobile phones and cars.

The internal memory is generally divided into two or more categories: writable working memory, and data memory respectively semi-permanent program memory, and sometimes more variants. It is common that the working memory ("RAM") is substantially smaller than the program memory ("ROM").

The programs are written on personal computers in assembly language, or high level languages like C, C++ and Basic. The transmission to the microcontroller’s program memory is called programming.

Table 13: Microcontrollers

BOARD	INPUT VOLTAGE	FREQUENCY	DIMENSION	PRICE
ARDUINO UNO-R3	6-20 V	16 MHz	7.6 x 6.3 cm	19.61 €
ARDUINO PRO MINI	5-12 V	16 MHz	3.3x 1.8 cm	9.95 €
MSP- EXP430G2	1.8-3.6 V	16 MHz	6.8 x 5.1 cm	4.95 €

- Arduino Uno-R3 is based on Atmega328 microcontroller and have 14 digital I/O Pins (6 pWM outputs), 6 analogue inputs, 32 k flash memory and 16 MHz clock speed (Figure 5).

- Arduino Pro Mini is based on the ATmega168, it has 14 digital input/output pins, 6 analog inputs, an on-board resonator, a reset button, and holes for mounting pin headers. This board is intended for semi-permanent installation in objects or exhibitions, and it is suitable for small projects that do not require large processing capability.

- MSP – EXP43G2 LaunchPad is based on the MSP430G2x Value Line Microcontroller Units, this 10 board offers ultra-low power consumption, 16 kB flash, a 512 B SRAM and 20 pins. This device features a powerful 16-bit Reduced Instruction Set Computer (RISC) central processing unit (CPU), 16-bit registers, and constant generators that contribute to maximum code efficiency.

The MSP-EXP430G2 was the cheapest one but the input voltage was so low on that one so for our case it would have meant that we had to have an extra power supply for this microcontroller and that would have meant an extra cost and also a component that would have taken more space. The Arduino Mini and Arduino Uno-R3 is quite similar in function but Mini is based on ATmega168 and Uno-R3 is on ATmega238, and the main difference is that you have the double programming space on the ATmega238. For the mini we would have needed an extra power source for the servomotors, that's why we chose the Arduino Uno-R3 because it can be powered through the USB connection or with an external power supply, and also the our motor shield Ardumoto is perfect fitted for the Arduino Uno-R3.

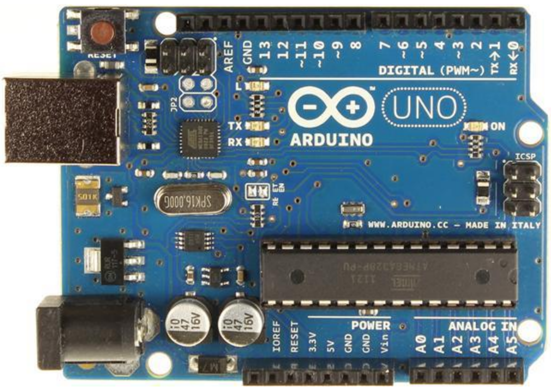


Figure 5: Arduino Uno-R3

2.9 Motor Shields

To control the DC motor POL-994 we need a motor control system because the DC-motor needs more current that the microcontroller can provide, and the developers for POL-994 suggest a couple of solutions like any L293 or other H-Bridge controllers, the Arduino Motor Shield or the Ardumoto.

- The Arduino Motor Shield is based on the L298, which is a dual full-bridge driver designed to drive inductive loads such as relays, solenoids, DC and stepping motors. It lets you drive two DC motors with your Arduino board, controlling the speed and direction of each one independently.

- This is a motor shield for Arduino that will control two DC motors. Based on the L298 H-bridge, the Ardumoto (Figure 6) can drive up to 2 A per channel. The board takes its power from the same Vin line as the Arduino board, includes blue and yellow LED lamps to indicate active direction, and all driver lines are diode protected from back EMF.

- We chose to use the Ardumoto or the Arduino motor shield because they are already fully assembled and both fits perfect for the Arduino one R3. Both of them have similar features and they can operate two motors at the same time if it is needed, but the Ardumoto uses the Arduino one R3's external power plug and the Arduino motor shield needs an own external power source [**40**].

Figure 6: Ardumoto motor shield

2.10 Batteries

Battery cells come in two basic types, namely primary and secondary cells (disposable batteries and rechargeable). The term primary cell derived from that cell type is the primary source of electrical power and is not designed to be recharged. Primary cells convert energy from a chemical reaction into electrical energy that goes on until it is used up.

In the secondary cell is transformed in the same way the energy of the chemical reaction into electrical energy and the rearming enables the process of going in the opposite direction. By using different types of anode and cathode materials and electrolyte obtained various properties of the battery cell.

Different battery types:

- Nickel cadmium - NiCd – using nickel oxide hydroxide and metallic cadmium as electrodes, the NiCd is used in applications that require long life, high discharge rate and low price. Main applications are two-way radios, biomedical equipment, professional video cameras and power tools. The NiCd contains toxic metals and is not environmentally friendly.

- Nickel metal hydride - NiMH – This type of rechargeable battery uses positive electrodes of nickel oxyhydroxide (NiOOH) and the negative electrodes use a hydrogen-absorbing alloy. NiMH batteries will not perform well in high rate discharge applications, typically providing only a small fraction of the rated capacity in these instances. NiMH batteries have higher energy than NiCd battery, but they have higher self-discharging rate and shorter shelf life.

- Lithium ion - Li-ion – Emerged in the early 90’s, it has a high energy density, a relatively low self-discharge rate, no need for maintenance as well as the ability to provide high current to a system. This type of battery has some limitations, mainly in its maturity and the requirement for a protection circuit in order to maintain the voltage and current within the safe limits. The Lithium ion chemistry is lightweight, does not contain toxic metals like the lead acid batteries and lasts long enough to span the typical life of the product.

- Lithium polymer - Li-Po – Similar to the Li-ion batteries has its main advantages by being lightweight, very low profile, resistance to overcharge and the low chance for electrolyte leakage. On the other side of the scope it may become more expensive than the Li-ion as far as the cost-to-energy ratio may concern.

- Lead acid battery - is the oldest type of rechargeable battery. Despite having a very low energy-to-weight ratio and low energy-to-volume ration its ability to supply high surge currents means that the cells have a relatively large power-to-weight ratio.

- Nickel- Zink - Ni-Zn is similar to the other nickel based batteries in that they use an alkaline electrolyte and a nickel electrode, but differs in voltage. The gain in voltage means reduction in cycle life. Ni-Zn batteries do not consist of any heavy toxic materials and can be recycled.

We will use a lead-acid battery because they are heavier so we won’t need so much extra weight inside the fish and they are also a little bit cheaper, the operation voltage for all the components will be 6 V so we will use a 6 V battery.

2.11 Outside Control

Radio control is the use of radio signals for remotely controlling a device. The term is often used with regard to radio-controlled models are controlled from a handheld transmitter (Figure 7a). Examples of radio controlled models, model cars, model boats, model helicopters and model aircraft. Besides that industrial, military, and scientific research use radio control, such as satellites and space probes. The military has also begun to ripple on various missiles and torpedoes.

Radio controls designed for hobbying usually use the 2.4 GHz or 35 MHz, and 27 MHz, but under water radio controls do not work so we have decided to make a control with a cable.

We are going to use a project case (Figure 7b) from sparkfun, and we will use a PCB eurocard and solder 4 buttons and one potentiometer to control the movement of the fish. We will need a cable with 8 threads because to get the buttons to work they need plus, ground and one for the signal.

Figure 7: (a) Remote control and (b) case

2.12 Conclusion

The purpose of observing state-of-the-art products was to gather the knowledge required to successfully design and implement a biologically inspired robot. Several natural and manmade mechanisms and products have been presented and compared. The innovative character of the toy in the market has been confirmed, due to the products unique combination of educational values. Suitable electrical and control modules could already be chosen at this state.

Based on this groundwork, the chances are high that the newly developed product fulfils technical expectations (1.5) and can be placed in the market successfully.

3. PROJECT MANAGEMENT

3.1 Introduction

To finish the project “Swimming Robot” successfully with the given resources and in the available time, a careful management is essential. Providing an overview of the most relevant in- and output data concerning the project, as well as agreeing on tools to organize the project´s course and special events, help to work more efficiently. Also, it is a positive contribution to the working atmosphere if all team members feel that everything is planned thoughtfully. A general optimism about successfully finishing the project helps every individual person to perform better.

In this chapter, it will be presented how our team applied the main issues of project management to our project. They are management of the project´s scope, time, cost, quality, people, communication, risk, procurement and stakeholders.

3.2 Scope

The section on scope management provides a description of all required deliverables in order to keep in mind the objectives of the project.

The targets of the project “Swimming Robot” are to design a marketable product, implement a prototype and to evaluate functionality tests performed with it. In addition, the following deliverables have to be developed, documenting the project´s process and achievements: This report, a paper, a leaflet, a poster and a video.[3]

The *final product* is going to be a construction kit for children in the form of a fish-like swimming robot. It will provide the opportunity to develop three skills: Children can (1) get to know mechanical structures of robots by self-assembling the product, (2) learn basic informatics skills by programming the control module oneself and, lastly, (3) experiment on the physics of objects submerged under water by changing several propelling and static components. The product´s concept provides an innovation in the toys market because of its diverse educational value. A marketing plan (Chapter 4) will elaborate on these ideas in order to place a successful product on the market.

[3] All deliverables are available on the team´s wiki.

The *prototype* is aimed to incorporate a set of functionalities, allowing it to work and be controlled not only on the surface but also under water. The detailed technical requirements towards the prototype are listed in section 1.5 Requirements. It is tried to fully comply with the requirements during the project development (Chapter 7). The implemented prototype has to pass functionality tests in order to find out if a newly designed tail-propulsion-mechanism (7.3.2) will be a scientific innovation.

After developing this report, a scientific *paper* needs to be created to sum up the achievements of the project. The *leaflet* shall promote the final product to future customers, whereas the *poster* should inform the viewer more about the product´s technical aspects. Finally, the *video* focuses on the team working together throughout the development, implementation and evaluation of the prototype.

Based on the description of deliverables a list of work assignments was developed. The specified tasks and their allocation are presented in Table 2(1.7 Project Planning).

3.3 Time

Time management is an important matter for the project in order to finish all deliverables in the desired quality at the required date.

In Table 14, there are displayed the deadlines for deliverables, which were predetermined by the EPS coordination.

Table 14: Deadlines for project deliverables

DELIVERABLE	DEADLINE
Upload interim report and presentation	06-04-2014
Interim presentation	10-04-2014
Hand in list of materials for implementation of prototype	26-04-2014
Upload final report, presentation, video, paper and poster	12-06-2014
Final presentation	19-06-2014
Make final corrections to the report, according to received feedback	26-06-2014

Based on this set of deadlines, an outline of all the work that needed to be performed for the project was developed. After specifying the work assignments, the available project time was distributed. The Gantt chart clearly arranges all required work assignments and their durations and marks the deadlines as milestone events (Figure 1, 1.7 Project Planning). Since it was not possible to make a detailed and accurate plan for all activities in advance, the Gantt chart has been repeatedly revised as the project proceeded.

In addition, a website for task management (3.7.2) helps to overview the work progress. The website allows to define tasks, set deadlines and allocate responsible persons. Every member can tick off completed tasks, so that others can see what has already been done and what requires more work.

3.4 Cost

Cost management is the process of planning and controlling the budget of a project. The budget for this project is 500 € and is provided by:

ITSECTOR – Sistemas de Informação, SA
Rua José Falcão, 151 – 1° / 2°
4050-317 Porto.

Our project includes direct and indirect costs. The indirect costs concern the overall working conditions (University facilities like classroom with computers and laboratories; salaries for supervisors, teachers and technicians) and are covered by EPS. That is why our project budget is only spent on the costs directly related to our project. Because of our student status and the project´s educational character there are no salaries for the team members.

The budget is only used for paying the expenses for prototype materials. They need to be selected carefully to keep costs low but also maintain high quality. The list of materials is elaborated throughout the project development (Chapter 7) and summarized in Table 42. The total amount of money required for materials is at least **270 €**. That gives the project a safety margin of 230 € for unexpected events.

3.5 Quality

In order to build a prototype that complies with the initially set requirements and to finish every deliverable in a quality that meets the team members´ expectations and also the EPS standards, every work produced for the project needs to pass a quality control. In quality control there are two dimensions involved: The human aspects consider how well each team member performs on individually allocated tasks, whereas the technical aspects involve how accurate the product is developed and implemented. In this project the biggest technical quality issues are concerned with *waterproofing* the robot´s body against water leakage and making the complex *tail mechanism* work. The realization of these key issues decides on whether the prototype works as expected or not.

The quality of each performed task, in the human and technical dimension, is firstly being controlled by the team and secondly by ISEP professionals.

3.5.1 Team-Internal Control

Due to our diverse professional backgrounds, experiences and personal interests we cover a wide range of viewpoints and skills (3.6 People). That is why already a high level of quality can be achieved if team members double-check on each other´s works. Especially work results that are of high importance to the project need the approval of the entire team, for example major structural decision throughout the product development. A possible tool to keep an overview over task assignments and their progress is using a tabular system as presented in Table 15.

Table 15: Quality control table (team-internal)

TASK	DEADLINE/ DURATION	RESPONSIBLE TO PERFORM	EXPECTED RESULTS	PROBLEMS	RESPONSIBLE TO DOUBLE CHECK	CONCLUSION
…	…	…	…	…	…	…

Furthermore, all documents concerning the project are shared with the team in a synchronized online folder. This way every team member can overview at any time how the work processes in terms of quantity and quality. This way, help can be provided if there are detected any problems in achieving the expected results. Every team member should review every deliverable and provide feedback to the responsible person before the final deadline.

Successful communication is an essential contribution to enhance the quality of the project. In order to document all assignments in an adequate manner, suitable tools for each task, namely computer programs, needed to be selected, as presented in Table 16.

Table 16: Computer programs used for performing tasks

TASK	PROGRAM
Create 3D model and technical drawings	Inventor
Program the control module	123d.schematic, Arduino 1.0.5
Display process of project	Dropbox, todoist, quality control table
Write report, create leaflet	Microsoft Word
Prepare presentations	Prezi
Create designs, edit pictures	Adobe Photoshop

3.5.2 Control through ISEP Professionals

In addition to our team-internal revisions, the professionals at ISEP control the project´s quality. The weekly meeting with the supervisors enables them to judge if the project is on the right track and correct mistakes by providing feedback. At the same time, the team has the chance to seek professional advice on challenging issues to ensure high-grade deliverables. The same applies to the lecturers. A milestone event is the Interim Assessment. It not only obliges the team to finish parts of the deliverables in an early project phase, but also gives the professionals the opportunity to analyze and correct our work. After the assessment, lessons learned can be applied to future task performances. That way, the quality of all deliverables continuously rises throughout the entire project phase.

Concerning the technical product development there are some supervisors, which are, based on their professional background (Table 23), responsible for double-checking the team´s work on specific areas, as presented in Table 17.

Table 17: Supervisor´s functions for controlling quality

SUPERVISOR	CONTROLLED TECHNICAL ASPECTS
Manuel Santos Silva	Functionalities of prototype and choice of components
Fernando Ferreira	Mechanical details (especially on tail mechanism and waterproofing), files for 3D printing
Paulo Ferreira	Electronic circuit, programming

3.6 People

The atmosphere within the team has a large impact on the corporation and therefore success of this project. Team-building activities allow getting to know each other, defining team roles and solving communicational problems.

The project can only succeed effectively if everyone involved shows motivation and contributes his/her part. In order to make the project also work efficiently, major work assignments were allocated to team members (Table 2) depending on our different professional backgrounds and skills. As the project proceeded, every person found his/her role in the team based on individual strengths, interests and personalities. In Table 18, there are presented expectations of the team members and their different roles and responsibilities concerning our project. The role names derive from the Belbin team theory [**41**].

Table 18: Team members´ expectations and roles

PERSON	EXPECTATION	TEAM-ROLE
Alicia	Learn how to develop a new product step by step in an international and multidisciplinary environment	Resource Investigator, Finisher, Team Worker
Magdalena	Learn how to coordinate different skills and interests to result in a successful outcome (hopefully a swimming and diving robot and satisfied stakeholders)	Monitor, Chairman, Company Worker
Marcin	- Produce a working robot (able to swim and dive under water) - Contribute own skills to build a prototype from scratch - Experience working in a practical project	Team Worker, Chairman
Rasmus	-Produce a working prototype -Get more knowledge about teamwork and skills in own field of studies	Team Worker

3.7 Communication

The success of a project depends on a careful communication with all people involved. Communication can be oral, written and non-verbal. In the next subsections, the oral and written communications applied to this project will be presented in detail.

3.7.1 Oral Communication

Oral communication is normally used in face-to-face meetings. It not only includes the usage of voice but also the attitude and body language [**42**].

In the project "Swimming Robot" face-to-face meetings are scheduled carefully and everybody can express what he/she wants to say. It is also important to know which are the targets of every meeting. Sometimes we meet up to argue about some specific topic or sometimes we meet up to work together. If our target is to make an important decision, we take care not to talk about others topics that are not useful for reaching the decision.

We have weekly meetings with the supervisors. Before the meetings, we write the questions that we have and upload them to the Wiki. This way, the supervisors can prepare the answers better. If any doubt is important and we cannot wait for the next meeting, we can write an email to our supervisors and arrange an extra official meeting.

3.7.2 Written Communication

Written communication is more precise and less subjective. We use written communication to talk among team members and to talk with our teachers if we cannot meet face-to-face. In Table 19, the communication tools applied for the different stakeholders at ISEP and their purposes are classified.

Table 19: Communication tools for stakeholders at ISEP

STAKEHOLDER	COMMUNICATION TOOLS	APPLICATION
Team Members	Dropbox	Share documents, team members can see work progress
	Whatsapp/Facebook Text messages	Inform the group about something (meetings, new tasks, general mistakes…)
	Todoist	Organize what, when and by whom has to be done
Supervisors	Email	Appoint meetings, ask questions (more formal and easier to organize all ideas or questions)
	Wiki	Supervisors can see the work progress any time they want (important to have a well-structured and updated Wiki that provides clear information)
Teachers	Email	Send files, ask questions and arrange extracurricular meetings

There are other stakeholders among the general public that are involved in the project. Table 20 shows the tools that we use to communicate with these stakeholders.

Table 20: Communication tools for stakeholders among general public

STAKEHOLDER	COMMUNICATION TOOLS	APPLICATION
Experts	Email/Website	Ask for information and opinions, arrange meetings
Suppliers	Email/Website	Research existing products, decide on suitability for prototype
Customers (Toy Companies)	Email	Try to sell product, arrange meetings
	Webpage	Show our product and attract customers
	Leaflet	Show the companies who we are and what we did
Consumers (Parents)	Surveys	Detect trends in interests, collect ideas
Final Consumers (Children)	User´s Manual/ Environmental Leaflet	Provide information about how the product works

3.8 Risk

Risk management is the process of identifying, analysing and responding to risk factors throughout the course of a project and in the best interests of its objectives. Proper risk management implies control of possible future events and is proactive rather than reactive [**43**]. Table 21 lists possibly occurring risks and our response tactics.

Table 21: Risk management chart

RISK	PROBABILITY (LOW/ MEDIUM, HIGH) AND IMPACT	PLAN/ RISK RESPONSE
Waterproofing problems	High. Was a problem in the earlier prototype. If water comes inside the body of the fish, the electrical components will be damaged.	Perform waterproofing tests without any components inside. Only fix all the components when the test results ensure that there is no risk of water leakage.
Tail mechanism does not work	High. We are developing a new system and have little experience in the robotic field. It is possible that our design doesn't work as expected.	Inspect all possible failures of the mechanism integrating every available expertise. Try to develop another system with available materials.
The prototype cannot dive	High. One target is not fulfilled.	Inspect all possible failures of the mechanism. Try to develop another system with available materials.
3D printer does not work as expected	Medium. Pieces for tail and body covers are missing/ of bad quality.	Try to find another 3D printer, cut (mill) components instead of printing
Team members are sick	Low. Depending on disease and recovery time allocated tasks cannot be performed.	If it is a serious situation, the person´s tasks will be redistributed among the remaining team members.
Late in Deadlines	Low. Last-minute problems may occur. Mark is downgraded.	Try to explain the problems to the supervisors/teachers.
Materials are not as expected	Medium. Prototype can not be implemented in desired way.	Try to find other low-cost materials to substitute the materials.

3.9 Procurement

All resources related to the project require management. They are people, goods and services.

3.9.1 People

First of all, there are people organising, working on and advising the project. The team members work on the project as a fulltime occupation. They control each other and work within the rules and guidelines of the EPS project and the supervisors´ and lecturers´ rules, advice and feedback. The detailed task allocation among the team members is to be found in Table 2 and contact details in Table 22.

Table 22: Contact details of EPS team 1

NAME	E-MAIL ADDRESS
EPS Team 1	swimmingrobot@gmail.com
Alicia Moreno Ishii	alicia.moreno.ishii@gmail.com
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The EPS provides a working environment, deadlines, supervisors and lecturers. Like this we receive information, advice and feedback. Information about professions and contact details are collected in Table 23.

Table 23: Information about EPS supervisors

NAME	PROFESSIONAL BACKGROUND	CONTACT DETAILS (E-MAIL, ROOM)
European Project Semester at ISEP		epsatisep@gmail.com
Abel Duarte	Chemical Engineering	ajd@isep.ipp.pt G204
Fernando Ferreira	Mechanical Engineering	fjf@isep.ipp.pt F329
Manuel Santos Silva (Project Advisor)	Electrical Engineering	mss@isep.ipp.pt manuel.s.silva@inesctec.pt F426
Maria Benedita Malheiro (EPS Coordinator)	Electrical Engineering	mbm@isep.ipp.pt F425
Maria Cristina Ribeiro	Physics	mcr@isep.ipp.pt H515
Paulo Ferreira	Computer Engineering	pdf@isep.ipp.pt B322
Pedro Barbosa Guedes	Mathematics	pbg@isep.ipp.pt H406

The lecturers provide professional information, advice and feedback. Their subjects and contact details can be found in Table 24.

Table 24: Information about EPS lecturers

NAME	CLASS	CONTACT DETAILS
Alberto Peixoto Pinto	Project Management, Team Building	apo@isep.ipp.pt
Ana Barata	Communication, Portuguese	abt@isep.ipp.pt
AndreiaTaveira da Gama	Marketing	atg@isep.ipp.pt
Luis Filipe Caeiro Castanheira	Sustainability	lcc@isep.ipp.pt
Luís Cardia	Ethics & Deontology	ldl@isep.ipp.pt

3.9.2 Goods

The team needs components to build the prototype. The required products are identified as a result of the product development process. The team has to search for suitable offers for each product. The EPS program demands to only use local suppliers. A list of materials (7.3.9) is to be prepared that specifies the supplier details, names of the desired items, numbers of units and costs. The EPS supervisors are responsible for the actual ordering, receiving and distributing process. Also they manage the team´s budget and take care that invoicing and payment is done via ISEP facilities. This ordering procedure is the only way the team can resort to the project´s budget.

If the procurement of some product fails, the team, with the help of supervisors, will try to find substitutes already available at ISEP or buy additional material in local shops.

3.9.3 Services

During the implementation of the prototype the team cannot perform all works, but need to outsource certain assignments, e.g. for reasons of safety or quality control. Table 25 lists the required tasks and to whom the team assigned the responsibility to perform it.

Table 25: Outsourced services for prototype implementation

SERVICE	RESPONSIBILITY (EXECUTION)
Cut pipe	Technicians at ISEP
3D printing - Tail segments - Pipe caps (plane) - Aluminium rods for waterproofing - Support structure for parts inside shell	Fernando
Machine (plastics & aluminium)	Technicians at ISEP
Create spherical pipe cap	Manuel

The contact to the specific technicians at ISEP is established through the supervisors. Delivery dates are set throughout the course according to the available time as presented in the Gantt chart (Figure 1). The supervisors handle the labour costs for ISEP´s technicians.

3.10 Stakeholders Management

The stakeholders of this project are team members, supervisors, experts, customers and users. They take interest in the project and can influence expectations, the scope of project development and deliverables.

At first, all stakeholders´ expectations towards the project were identified. The team member´s individual expectations were already displayed in the people´s management chapter (Table 18). Furthermore, the professionals at ISEP, which are supervisors and lecturers involved in the project, have specific expectations towards the project, as shown in Table 26.

Table 26: Expectations of professionals at ISEP

FUNCTION (S = EPS SUPERVISOR, L = LECTURER)	PERSON	EXPECTATIONS
S	All	- Learn how to develop a project in an international team (focus on process of teamwork and project management)
S, Project Advisor	Manuel Santos Silva	- Implementation of a swimming robot that is able to dive
L: Project Management and Team Building	Alberto Peixoto Pinto	- Accurate elaboration and execution of project management issues; - Gathering of knowledge about different cultures, especially the Portuguese one; - Experience to work out a project on one´s own authority and to finish it despite all obstacles.
L: Communication and Portuguese	Ana Barata	No answer received to request.
L: Marketing	Andreia Taveira da Gama	No answer received to request.
L: Sustainability	Luis Filipe Caeiro Castanheira	- Rise of the team´s level of engineering competences - In particular acquisition of competences related to the sustainable design of products and services
L: Ethics & Deontology	Luís Cardia	No answer received to request.

Finally, also the expectations of stakeholders, which are not from the academic environment, need to be considered. They are listed in Table 27.

Table 27: Expectations of stakeholders among general public

STAKEHOLDER GROUP	PERSON/INSTITUTION	EXPECTATION
Customer	Toys Companies	No answer received to request.
Consumer	Children	See results of survey in the marketing plan (Chapter 4).

To sum up all expectations towards the project, there are main targets that the team should acquire, which are closely related to each other: First of all, the team has to learn how to collaborate successfully, especially how to manage its human resources. Only that way, also the other aims can be reached in the available time. They are the implementation of a working prototype and the delivery of adequate documenting files, as listed in the scope chapter (3.2).

The elaboration of the prototype is noted down in the Project Development chapter (7) for everyone to reproduce. If there are any major changes in the project´s scope or problems in fulfilling expectations, these issues have to be managed in collaboration with involved stakeholders.

3.11 Conclusion

Based on the objective of organizing the project well in order to create a positive, effective and efficient working atmosphere, the team put effort in understanding and applying management tools to the project. In the beginning, the obligatory task allocation and Gantt chart were created. Throughout the project´s course we elaborated more management tools that seemed like helpful contributions. This way, our efficiency increased step by step. To highlight some aspects, we considered it helpful to be more aware of the project´s and individual task´s expected results. This helped to decide which issues to spend more energy on. Also, little contributions like collecting all contact data of stakeholders in a table saved us a lot of time. The most important issue for our team was managing quality control. The approach of creating a table for performing team internal double checks was only introduced in a late project stage. We are now aware of the importance of that tool and will be able to apply it to future works.

4. MARKETING PLAN

4.1 Introduction

Buying educational toys for children has become more and more popular among parents. There is evidence that children who play with construction toys have better spatial ability and creative capacity. Children learn a lot from playing therefore, making education enjoyable will help them to remember the things they learn and develop a positive attitude towards learning.

The world of toys is very competitive; there is a wide variety of products for the customer to choose. The goal of the marketing is to identify customers' needs and meet those needs in a way that the product almost sells itself. In this chapter the keys for the marketing plan are identified and detailed.

To help us to achieve better results a survey for twelve years old kids was done. Twenty-one youths from "EscolaSecundária do Agrupamento de Escolas de ÁguasSantas" from Porto in Portugal, were asked. The original questionnaire is attached in the appendix (number 1) and the results will be presented in the next pages.

4.2 Product Presentation

"Bro-Fish" will be the name of the final toy based in the prototype of the "Swimming Robot Biologically Inspired" that will be assembled during the month of June at ISEP. "Bro-Fish" is an educational construction kit. It has several features:

- Fish-like movement
- Remotely controlled (left/right and up/down)
- Easy to program
- Learning about physics of motion in the water by customizing parts

Children can follow these guidelines to start enjoying with the toy:

- Assemble the toy following the user manual.
- Program it according the different levels that are available using the templates that are provided.
- Experiment in water changing the customizable parts like the fins and the tail and of course, play.

It is not only a toy, but also an experience of experimenting with physics and robotics. Children can learn while playing. In the appendix (number 2), there is attached a guide for children to experiment on the physics of their “Bro-Fish” floating in the water.

In a world where most consumers have a wide variety of potential business to choose from to meet their needs, the initial interaction with a brand often is the most influential. To make our bran known, a good logo is essential. In the Figure 8 the “Bro-Fish” logo is presented.

Figure 8: “Bro-Fish” logo

4.3 Market Analysis

The Market Analysis presents information about the commercial market in which a product will be launched. It is based in a market research and intended to attract investors. A strong Analysis will show why our business is a strong addition to a given market. The Market Analysis is composed of the Macro Environment and the Micro Environment.

4.3.1 Macro Environment

The macro environment includes the major external and uncontrollable factors that can influence a business. These factors typically are the economical, demographical, political and legal, technological, socio-cultural and ecological environment.

It is important for a company to study its environment in overall to define the best possible target-marketing plan.

Economical Environment:

The European Union (EU) is the largest toy market in the world where consumers spend a total of 16.5 billion Euros on toys in 2011, followed by the United States 15.6 billion Euros, Japan 4.3 billion Euro, China 3.9 billion euro and Brazil 2.2 billion Euro. The EU toy market represents 28% of the worldwide traditional toys' and games' sales. Despite the current crisis in the EU, the global toy purchasing is projected to rise by about 7.5% annually until 2016 [**44**].

Nowadays games, puzzles and pre-school toys are the most popular type of traditional toys but it should be pointed out that construction toys were growing fastest in terms of sales in EU countries [**44**].

The toy business is seasonal. More than 50% of the year's sales are done in November and December, especially in the countries of southern Europe.

Another important fact for the economic environment is the impact that toys have in the employ. There are some 5.000 toy companies within the EU, employing 220.000 people in this sector. Toy companies generate employment at a local level and therefore growth within the local economy [**45**].

Demographical Environment:

The population is often split into different market groups that can be targeted individually. In this chapter the age of the consumers and the European target countries are analysed.

Age of consumers: By the age of six kids have developed the cognitive abilities to follow directions and to understand step sequences. By the age of seven to eight years some children can build structures using sets with moving, motorized, or computer chip-based components. As a rule, the containing parts of the kits must be very wide in size, colour and shape to increase attractiveness to children. Construction kits must have at least 100 pieces to provide sufficient material to create own designs [**46**].

Recent reports show that the number of children of fourteen years old and younger has been decreasing in the EU over the past decade. Nevertheless, the purchase of toys is rising because of a *growing senior population*, that likes to spend money on grandchildren, and *increasing divorce rates*, that make children member of two or more different families [**47**].

On the basis of the above, the construction kit "Bro-Fish" will meet of children between eight to twelve years old.

European target countries: To get a successful result, are some aspects of the different countries of the European Union that must be studied. In the next Table 28 two important parameters like the money that the parents spend per child every year in toys [**48**], and which are the most important sales points in every country [**49**] are described.

Table 28: Representative countries in toy's sales

COUNTRY	MOST IMPORTANT SALES POINTS	AVERAGE AMOUNT SPENT PER CHILD ON TOYS IN 2011
GERMANY	1. Very decentralised. 2. Thousand of independent stores.	290,46 €
FRANCE	1. Dominated by "Hipermarché". 2. Followed by toys specialised Toys chains.	299,22 €
UK	1. Dominated by "Argos". 2. Followed by Grocery and by toys specialised Toys chains. 3. Strong online sales.	364,17 €
SPAIN	1. Dominated by "Hipermarché". 2. Followed by "El Corte Inglés"	153,26 €
ITALY	1. Dominated by "Hipermarché". 2. Followed by toys specialised Toys chains.	161,29 €

At this time, Germany is the fifth largest economy in the world and Germans are the third Europeans who more money spends per year in toys. It is for our company a great market opportunity to introduce our product in a near future.

Political/Legal Environment:

The political environment in which the company operates has a significant impact on its international marketing activities. A company that is continuously aware of shifts in the government´s attitude and keeps up with frequently changing laws and regulations, will be able to adapt marketing strategies according to that.

The political environment is connected to the international business environment through the concept of political risk, that is the risk of losing money due to changes that occur in a country's government or regulatory environment.

Another key point are the taxes that the European Commission determines for exports and imports. On the European Commission´s website "Trade Market Access Database" there are stipulated all import/export duties and taxes, procedures and formalities, trade barriers and sanitary and phytosanitary issues depending on the "Product Code" and the country [**50**].

In the EU toys are the product with the most notifications for regulatory non-compliance. The most frequent notifications are related to small parts (a choking hazard) the second most frequent are related to chemicals in toys exceeding regulated threshold values. The number of warnings issued in 2013 was 3.8% higher than in the previous year. The Commission attributes this increase to improved detection and enforcement by national surveillance authorities, rather than a rise in the number of dangerous products being distributed in Europe [**51**] [**52**].

On 30th June 2009 a new Toy Safety Directive, Directive 2009/48/EC, was published. The EU member states had to apply the new measures starting from 20th July 2011; except for annex II part III (chemical requirements). Directive 2009/48/EC applies to toys defined as "products designed or intended, whether or not exclusively, for use in play by children under 14 years of age". It substantially amends the old directive in almost every safety aspect, fulfils the newest health and safety standards to the highest level. It also improves the existing regulations for toys that are produced in and imported into the EU in order to reduce toy related accidents and achieve long-term health benefits [**53**].

<u>Social Environment:</u>

All types of games play a decisive role in the development of children. With adequate games children stand best chances of becoming healthy, happy and productive members of society. Kids who do not play or who do not have the opportunity to play cannot adequately develop self-control. Over time, kids are to discover what they are good at, what they like, and what they are like, then they will need variety in their gaming experience and a broad assortment of toys to make that possible.

Toys are of essential importance when kids establish their first social relationships. Parents are the first playmates of the infants, but once children reach school age, they spend most of their playtime with mates [**46**].

<u>Technological Environment:</u>

The toy industry is very innovative and companies invest a lot of money in market analysis, research, development and intellectual property protection. 60% of the toys in the market are new products each year. In 2011 90% of the companies launched a new reference, a percentage that in other industries drops to 40%.

It is also important that video games are becoming a substitute for traditional toys, especially when children are a bit older. The recent rise of crossover toys that combine video games and mobile games and apps with traditional toys offers new market and technological opportunities for traditional toys and games to benefit from the rise in popularity of modern communication technology [**44**].

Ecological Environment:

An extremely wide variety of materials are used in toys, and some of them contain Phthalates, BisphenolA, harmful substances for humans and the environment.
Special care must to be taken with the batteries and the plastic shell that will be used in the final toy. To try to reduce the damage that the battery and the plastics can cause to the environment, an "Eco-friendly Plan" will be studied. This Plan consists in encourage our clients to return the toy to the Toys shops once the toy's life is over.

Also, inside the box of the toy, we want to incorporate a small environmental leaflet. In the leaflet, the ocean's problems will be presented to the kids. The target is to make children think about how important the oceans are.

4.3.2 Micro Environment

The Micro Environment is made up of factors close to a business that have a direct impact on its business operations and success. These factors are suppliers, intermediaries, customers and competitors.

Suppliers:

Suppliers are firms and individuals that provide the resources needed by the company and its competitors to produce goods and services. There is a huge variety of toy piece suppliers at a national and international level. For the implementation of our prototype we bought many components on the online stores of the companies Mouser Electronics and InMotion because of their wide range of products and reasonable prices.

Intermediaries:

At the moment our target is the "Business to Business" market. The toys market is a very old market with lots of strong companies worldwide. A small business can hardly compete with only one product for sale. A new brand of construction toys could be created in the future operating mostly online to keep costs low. It is presumed though that the idea of a "Swimming Robot" has better chances to be sold to a toy company rather than selling it directly to the final consumer.

Customers:

We set the main customer to be toy companies. There are plenty of them in the market and they are constantly looking for new ideas to develop and improve their toys or to create new ones.
There are some companies specialized in construction toys that are the most interesting to try to sell the “Swimming Robot”.

- Mattel. The toy gigant is deeply involved in toy construction. They announced a $450 million purchase of Mega Brands, a Canadian maker of construction toys and arts and crafts. Mattel CEO Bryan Stockton, said "The construction play pattern is popular, universal and has one of the fastest growth rates over the past three years."
- Tamiya. The japanese company has a “Waterline Series” and an “Educational Construction Series” Lineup. Some products are similar to the “Swimming Robot” but do not have a remote control.
- LEGO. Mindstorms Lineup. LEGO blocks combined with advanced technologies can create remote controllable robots. At the moment there is no robot in the lineup of LEGO which is waterproof and thus can be operated under water. The “Swimming Robot” could serve as a good main idea to develop a new toy and expand LEGO´s existing product portfolio.

Consumer:

A recent survey reveals that parents have two main selection criteria when buying toys for their children: they search for the lowest price of toys the kids want and/or try to ensure a high educational value of the toy. Also Char Kochersberger, Toys 'R' Us store manager said "*Parents are coming more for the learning toys as opposed to the fun toys*". To sum it up, parents´ interest in buying educational toys is growing fast.

The 100% of the kids that were asked in the survey had played with construction kits. That mean, that parent at least once, had bought educational construction toys. To be more exact, we asked if about specific toy’s brands and the results were the following, Figure 9.

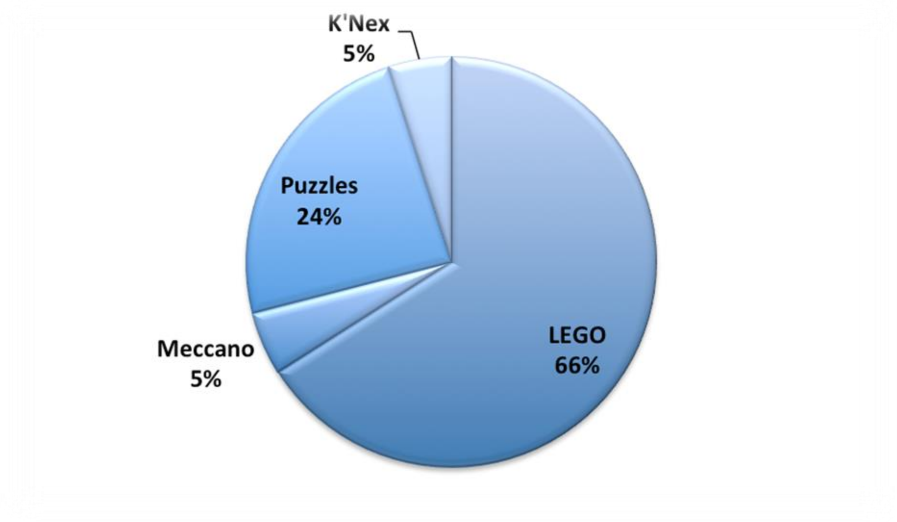


Figure 9: "Have you ever played with…?"

Most of kids had played with LEGO. As was explained in chapter 2. State of the Art, Construction Kits, K'Nex blocks has more possibilities to create construction structures and dynamic shapes. But LEGO is the most popular brand in construction toys. It is good for our company study carefully what is LEGO doing well and what are the strengths concerning LEGO's Marketing Plan.

Final Consumer:

In the European Union there are 78 million children that are the toy´s final consumers. They have to like the "Swimming Robot" because they are the ones who ask their parents for it.

According to Gizmag, an emerging technology magazine, the following toys are the five favourite for kids in the technological field [**54**]. These toys are displayed in Table 29.

Table 29: Five favourite technological toys for kids

TOYS	DESCRIPTION	FEATURES	PRICE
1. SHPERO 2.0 [55] 	Programmable ball	1.Roll on smooth, flat surfaces and carpet 2. Can also float and spin in water. 3.Smartphone-controlled toy 4. Compatible Android and iOS 5. Multicolors LEDs	94.53 €
2. ANKI DRIVE [33] 	Smart car	1. Can drive by themselves 2. Compatible with iOS 3. Battle mode. Players get to fire virtual pulse weapons or tractor beams at other cars on screen which disables or slows down the real-life cars	50.90 €
3. LITTLEBITS [34] 	Electronic Building Blocks	1. Can attach to each other and create cool stuff with them 2. Can combine them with ordinary objects	72.00 €
4. UBOOLY [56] 	Plush toy	1. Listens and responds to a person's voice. 2.Has an iPhone or iPod Touch zip into the cuddly body. 3.Learning toy.	43.60 €
5. LEGO MINDSTROMS [30] 	Robotic toy / Construction toy	1. Construction experience. 2.Control your creations with a remote or from your smart device via Bluetooth. 3594 bricks and a variety of sensors.	254.50 €

The conclusion that can be taken of this research is that between the favourite toys of kids, there are also educational toys. Spero 2.0 is a dynamic toy but also teach about programming to the kids. LittleBits has a very high educational value in electronics but it is not a dynamic game. Finally, the Lego's line up Mindstorms has high educational value and is a dynamic game, but the price that these toys have are much more higher compared prices of the other toys of the table.

A question concerning the about what kind of toys kids prefer was asked in the survey that we did in the Portuguese school. In the options that were given were "Books" and "Painting kits" and any child who did the survey chose these options. The interest in high technologies in kids in increasing as shows Figure 10.

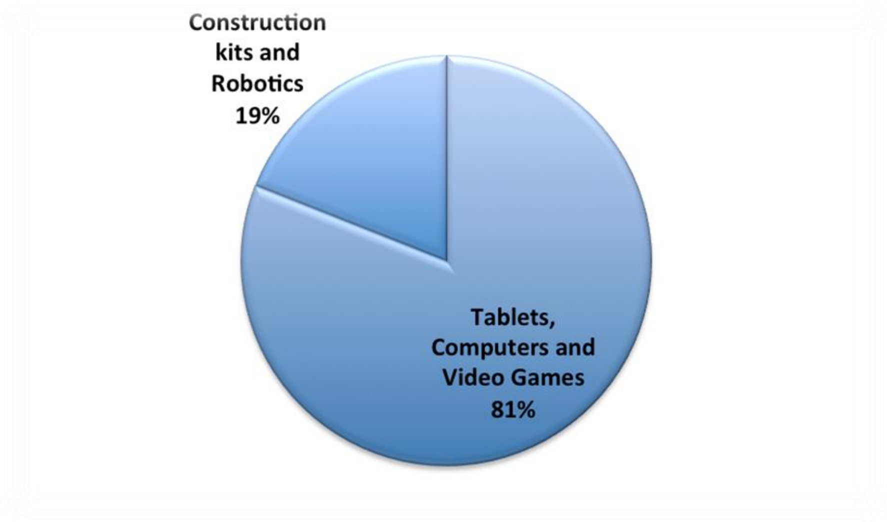


Figure 10: "Which of the following kinds of toys do you like most?"

Of course, traditional toys will no disappear, but we must take in consideration that the trend is the High Tech Toys.

Competitors:

The toy industry is nowadays one of the most competitive industries in the European Union´s market. Companies have realized that children are a very responsive market target. Due to a great amount of competitors it is advised to make use of patents to save intellectual property.

There are two main competitors:

- The companies to which we can sell our idea are at the same time our competitors. There are some similar products in the market right now. *Play-i* is a strong competitor. They have developed a good marketing plan and are having good results in sales. Also, *Tamiya* has two similar products in the market, but once you have built the robot you cannot change any components. In the following Table 30: Comparison of Tamiya's , the main aspects that are important for the Marketing Analysis are displayed.

Table 30: Comparison of Tamiya's robotic toy fishes

	TAMIYA MECHANICAL BLOWFISH [36]	TAMIYA MECHANICAL FISH [57]
PHOTO		
FEATURES	1. Swim in thesurface. 2. Waterproof	1. Swimunderwater. 2.Swim in circlesbychangingtheangle of thetail fin. 3. Waterproof.
EDUCATIONAL VALUE	Learn about Mechanics Physics in water	
BATTERY	Batteries AAA 4 h autonomy	
CONSUMER AGE	+ 10 years old	
PRICE	18 €	

- Other people that have same ideas to sell to the companies but we don't know who they are.

4.4 SWOT Analysis

SWOT is an analysis in which internal strengths and weaknesses of an organization as well as external opportunities and threats faced by it, are closely examined to define a strategy. By understanding the weaknesses of one business it will be easier to manage and eliminate threats.

Table 31: SWOT analysis

STRENGTHS	WEAKNESSES
New toy concept	Lack of knowledge in certain fields
Teach robotics/physics/programming to children	Limited budget
Customizable toy	Lack of time to improve the prototype
Sell a toy and an experience at once	Difficulty of finding customers
Add more functions to the toy later	
OPPORTUNITIES	**THREATS**
The toys market is growing	Big companies already control the market
Market for construction toys in Europe is growing faster than other countries	Competitors´ low prices
Children become more interested in robotics	Advertising plays a key role in this market

4.5 Goal Setting

The company's long-term goals concerning the product need to be established. These objectives are set for five years and must be realistic. After setting the targets it is still necessary to keep investigating constantly if there are targets missing or market needs changing.

- Create a new brand for toys.
- Increase the range of toys. Every year our company will develop one new toy that will come into the market in October/November to be always available on Christmas season
- Develop a website with the possibility of online sales.
- The technical assistance of the product will be available at the same time that the product.
- Develop compatibility of the toy with mobile applications.
- Lower prices by increasing the amount of sales
- Reduce production costs for better profit margin
- Investigate new possibilities for intelligent toys

4.6 Segmentation

The market segmentation helps companies to better understand the needs of customers. Drawing a conclusion to the previous market analysis and the SWOT analysis, it is interesting to construct a toy that can teach physics, robotics and programming.

4.6.1 Age Segmentation

There are toys for the following age segments: infants, toddles, pre-school kids, pre-teens, teens (12 years and above) and adults / parents.
When children are six years old they have developed the cognitive abilities to follow directions and to understand step sequences. Reaching an age of 13 or 14 or older they begin to be more interested in video games. Experts recommend construction games for children of an age between nine and twelve years because they begin to define their personality and interests by interacting with their environment [**44**].

In the survey, the question "What do you prefer to do in your free time?" was asked. As the Figure 11 shows, tree options was choosen. There was another option that was "Read", but no one choose it.

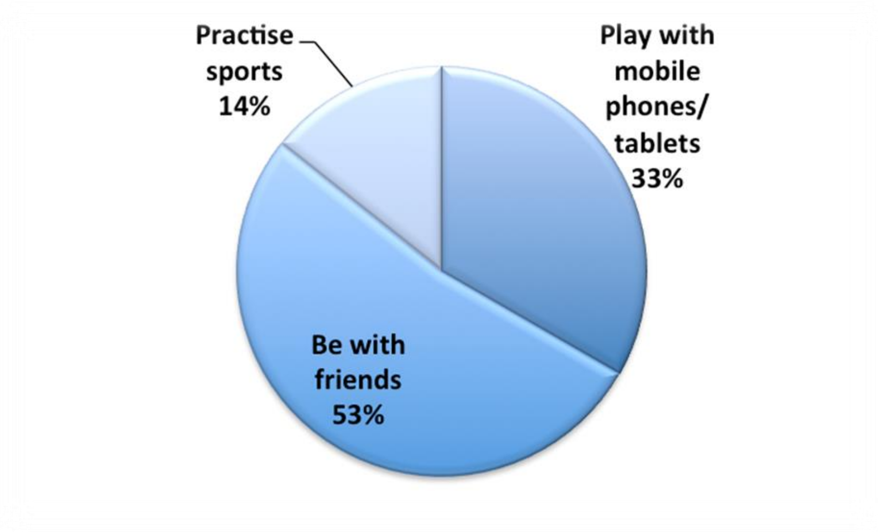


Figure 11: "What do you prefer to do in your free time?"

It is important to mention that nine of eleven kids that answered, "Be with friends" were girls. This suggests that twelve years old girls are more interested in social relationships that in toys. When these kids go getting older the interest in toys will be decreasing. The conclusion that can be drawn is that twelve years old should be the *age target limit* for play with "Bro-Fish".

Another interesting question for the Age Segmentation section was done. "What is the best thing about school?" was asked. In Figure 12 the results are displayed.

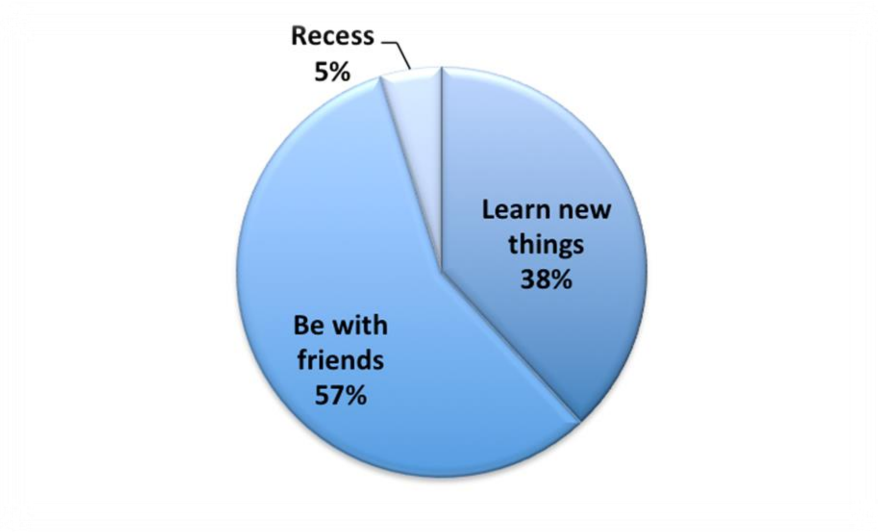


Figure 12:"What is the best thing about school?"

In this case, there is not a big difference between the girls and boys answers. It is a positive answer because this means that kids are interest in still learning. It is evidence the great important of the social relationships in this age range. However, to make "Bro-fish" a successful toy, the possibility of adapting any feature to the toy that can meet social skills should be studied.

4.6.2 Gender Segmentation

According to a recent market and industry analysis of Hasbro, the toy and game industry is dominated by products for boys. There are also plenty of toys for girls, but most innovations are achieved in the area boys´ toys. Children are outgrowing their toys much faster than they used to, and girls in particular outgrow toys aimed at their age groups faster than boys. Moreover, gender stereotyping by parents and society has an impact on children´s behaviour. This influences what types of toys are being manufactured [**47**].

In the section of Gender Segmentation, the survey made can help us to get meaningful conclusions. A question concerning about which are the professional fields that they like more was asked. The answers are in the following Figure 13.

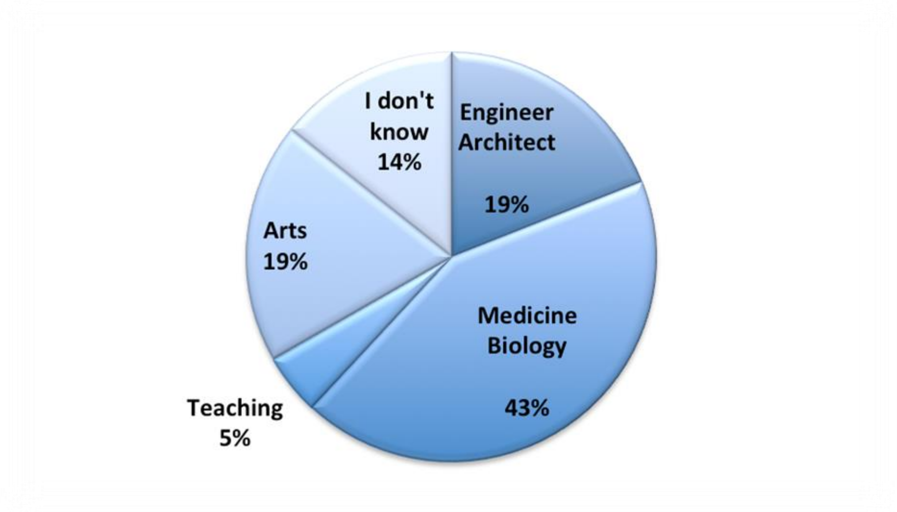


Figure 13: "Which professional field do you like more?"

All the kids that choose "Engineer/Architect" were boys. And also, in other question that was "Which is your favourite subject in the school?" only one girl chose "Mathematics/Physics/Chemistry" the others that had chosen this option were boys.

Another important fact can be taken, is about the question "How do you enjoy playing most?" The 100% of the kids that answered that they prefer to "Play alone" were boys. This means that of course, "Bro-Fish" should be also attractive also for girls, but our main target market will be boys.

4.6.3 Social Segmentation

Middle-class families in Europe represent the highest percentage in spending money on educational toys. That gives an idea at which kind of families the "Swimming Robot" should aim.

To sum up, taken into account the survey's results and the researches done, the Bro-Fish's market will be boys of an age range between eight and twelve years. Other feature that will be studied are the possibility of develop a system that can make "Bro-Fish" a social toy. If finally, this feature is developed, "Bro-Fish" will be more attractive for older kids and also girls will be more interested in it.

4.7 Strategy and Positioning

Positioning is a powerful tool that allows companies to create their own image. It is important to decide on the main characteristics, that our company is going to offer to the clients, because the toys market is very competitive.

4.7.1 Positioning in the toys features

The "Swimming Robot" differs from other construction toys because kids can still play and learn after the toy is completely built. Different parts of the robot, like the tail, the fins and the ballast of the fish, are customizable. Also, the toy has a high educational value. Playing with the "Swimming Robot" children can learn about:

- Physics: Kids can see the effects of changing certain parts of the robot`s shape and see how this effects the robot´s behaviour under water.
- Mechanics: Kids can build their own robot step-by-step getting to know the function of each part.
- Programming: Kids can learn the basic tools of programming. There are different degrees of difficulty: Copying a provided program code, using tutorials and templates to create a code, or developing a code from scratch.

4.7.2 Positioning through Price

Most of the educational toys in the robotic area, that teach more than one competence, cost around 100 €, for example play-I and Sphero 2.0. On the other hand, traditional construction toys cost about 20 €, as the Table 2 shows. The final price for the "Swimming Robot" toy could be targeted to 45 – 50 €, a price lower than the other robotics kits. The targeted price and estimated educational value of the "Swimming Robot" in relation to other existing products are displayed in the following Figure 14.

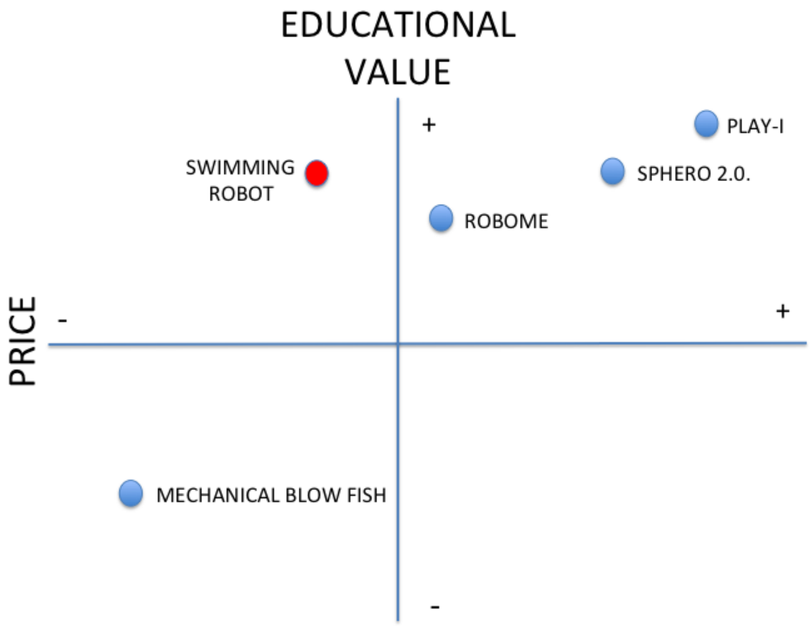


Figure 14: Market segmentation

4.8 Marketing Mix

The marketing mix is associated with the four P's: product, price, promotion and place. All elements that are included in the marketing mix influence each other. To create a marketing mix, market research needs to be done and several people consulted, for example users, suppliers and manufacturers.

4.8.1 Product

As was explained in section "4.2 Product Presentation", "Bro-Fish" is an educational construction kit for children. The main feature of the product is that it has a very high educational value without losing the attractiveness of a toy. Kids can learn during the entire process of constructing and playing with the robot.

Another feature of our product is, that in the future additional components for the "Swimming Robot" will be available. They can be bought separately and vary in their level of difficulty, regarding mechanics and programming. This way, the kids get the opportunity to never stop learning.

An important aspect is what kind of shape and colour will have the final toy. To help us with the kid's likes, two different questions were asked in the survey. The first one was "What type of animal do you prefer?"(Figure 15), and in the second one kids had to choose between four different photos of fish wich have completely different shapes.

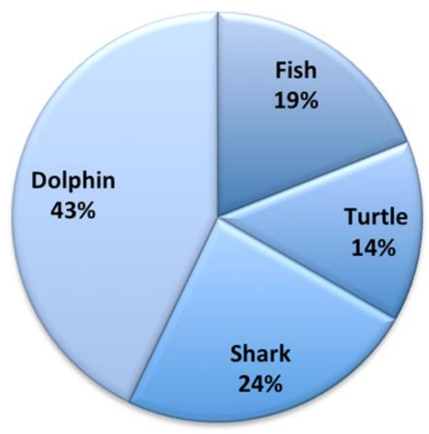


Figure 15: Favourite marine animals

Eleven of the twenty-one kids chose the dolphin and were both boys and girls.
"Bro-Fish" tail mechanism works to move to right to left, and the movement of the dolphin's tail is from top to bottom. In connection with the survey result, we thought in the possibility of only turning 90 ° the tail of the fish, transform the fish in a dolphin. In this

way, we can also give the opportunity to the kids to experiment changing the tail position. Of course, the hull and the fins (that are customizable) will change also.

About the second question concerning the shapes of the fish, the 90% of the children chose these options:

- The clownfish (Figure 16): The 57% of the kids chose this option. It is the most popular fish because most of kids that are in this age range had seen “Finding Nemo” by Disney Pixar. The clownfish colourful attacks the kids.

Figure 16: Clownfish

- The lionfish (Figure 17): The 33% of the kids chose this option. In this case, cannot be ensured that the shape of this fish can be achieved without a high increasing much the selling price.

Figure 17: Lionfish

As important as the product are the services offered. Often, a better service than the competition makes the difference. We want to foment the customer's loyalty and make "Bro-fish" the best chose for parents, kids and teachers. These are the services that our brand will offer:

- Technical assistance of the product: In the event of any piece breaks, the client can order just a specific piece. To make it easier, every piece will have a specific number code. All pieces will be available in the "Swimming Robot" webpage. "Bro-Fish" will be sold in Europe and must conform the European rules. In Europe the guaranty of the products last two years [**58**].
- "Eco-friendly plan": This plan consists in encourage our clients to return the toy to the Toys shops once the toy's life is over. This way, the pollution will be reduced and maybe any piece can be reuse.
- "Special Teaching Pack": "Bro-Fish" has a high educational value. And why not the schools and high school can teach programming, physics and mechanic with our product. "Special Teaching Pack" will be launched with special prices and with several guidelines to take advantage of all that "Bro-Fish" can teach.
- "Bro-Fish" Contests: To encourage kids to learn, several contests like programming contest and obstacle race in water and will be run.

4.8.2 Price

The price represents the product´s value. The final price of the robot will cover:

- Product development
- Materials of the toy
- Packaging
- Cost of labour
- Distribution of the product

At the moment, the definitive price of the "Swimming Robot" cannot be fully established. In order to approach the final price of the future product, firstly, the final production costs have to be accurately estimated. Therefore, three steps have to be taken: Assessment of prototype´s costs, definition of the actual final product´s components and calculation of possible money savings through mass production. After assessing these overall costs, the desired profit needs to be defined.

- The prototype*:* The price of the prototype was higher expensive because was compulsory to buy components that can be found in Porto. The final price that covers all the materials was 197.14 €.

- Actual final product's components: Once the prototype has been developed, component tests must be done. It is essential to know if there is any not necessary piece or any piece that can be replaced by other cheaper.
- Mass production of prototype: It is more expensive to build a prototype than to establish a mass production. Always the prices of the pieces will be cheaper if lot of them are bought. Also, the competence between the suppliers can favour the price of the pieces.

4.8.3 Promotion / Communication

Information needs to be provided in order to assist costumers in making a decision on purchasing a product or service. Only successful promotion can help improving the sales of a product, so that, in the end, the investment for promotion will more than "pay back" [**59**]. In our case, the customers are the toys companies.

There are different communication and promotion tools that we should use:

- Nowadays, it is important to have a website where our company can show the product. There are several free providers of webpages like www.ucoz.com. The provided information will be available in the languages English, German and Spanish.
- Social networks like Facebook and Twitter are helpful tools to promote our toy.
- Create a Youtube Channel. It's a great medium for product launches, demos, public relation communications, interviews, advertisements and tutorials.
- Via email with the Toy Companies.
- Product Demonstration in schools. This way, we can see the kids' reactions and we can take some ideas for the next projects.
- Toy Fairs that take place around the entire world, as the Table 32 represents [**60**], are a great opportunity to show our product. Face-to-face communication with our costumers, the toys companies, is a good way to make business. For example on 25thJanuary 2015, one of the most important German Toy Fairs, called "Spielwarenmesse", will take place in Nuremberg.

Table 32: European toy fairs

FAIR	WHEN	WHERE
BRINDE TOYS AND GIFTS EXHIBITION	04 Sep – 07 Sep, 2014	Porto, Portugal
SALZBURGERSPIELEMESSE + MODELLBAUWELT TOYS EXHIBITION	10 Oct – 12 Oct, 2014	Salzburg, Austria
INTERPÄDAGOGICA SPECIALIST EDUCATIONAL TRADE FAIR FOR TEACHING AIDS	13 Nov – 15 Nov, 2014	Vienna, Austria
SÜDDEUTSCHESPIELEMESSE SOUTH GERMANY'S LARGE EXHIBITION FOR GAMES	20 Nov – 23 Nov, 2014	Stuttgart, Germany
LIPPER MODELLBAUTAGE TRADE FAIR FOR MODELLING, TECHNOLOGY, HOBBIES AND HANDICRAFT	23 Jan – 25 Jan, 2015	BadSalzuflen, Germany
SPIELWARENMESSE NÜRNBERGTOYFAIR	28 Jan – 02 Feb, 2015	Nuremberg, Germany

- It might also be helpful for the promotion of our product to enter it into toy contests. These toys contest consist in create a video that explains how the toy was built and how it works. The webpage www.instructables.com offers different types of contests like the “Toy Challenge Contest”.

4.8.4 Place

It refers to the channel or the route through which products move from the source to the final user. Places could be the intermediaries, distributors, wholesalers and retailers. Choosing the right place to sell the product to the consumer ensures better sales over a long period of time. This translates into greater market share, more profits and greater ability to track the changes in consumer´s behaviour, regarding styles, fashion and needs [**61**].

In this moment, we only have one product developed, but in a near future we will have our own line up of toys. The most characteristic feature of our line-up will always be a high educational value of our toys. Of course, we have to start thinking in where places we will sell our products. Nowadays, selling online has a number of advantages over selling by conventional methods.

- Make savings in setup and operation cost. We do not need to rent a space and pay shop assistance.
- Reducing order-processing costs. Customer orders will automatically come straight into our orders database from the website.
- We will compete with larger businesses by being able to open 24 h a day, seven days a week.
- Being available on the Internet we can reach a global audience, thereby increasing sales opportunities.

Also, our toys will be available in different toy's shops. As was presented in Table 28, the German toys market is decentralized. There are many small toy shops are have to be studied. Every year, a "Sales Action Plan" will be develop. This Plan consists in analyze which are the most profitable stores, which are the products that are more sold and the German areas in which our brand has more impact.

Another way to sell our products are the shopping centres like "Toys r us" and "Imaginarium". In the shopping centres we will have a Trade Stand during the Christmas season, and every day we will make in-person demos of the toy.

4.9 Budget

It is necessary to estimate the projection of costs required to promote our product. The budget includes all promotional costs, which are leaflets, posters, videos, webpage and expenses for taking part in fairs. To keep expenses low, we chose a free server for a website.

The budget for the first year is 5000 €. At the moment we are not going to have any cost for the employing of the marketing staff, because we will develop all the commercial labours.

Important parts of our promotion are the Toys Fairs. This means that a significant proportion of the budget will be spend in travels. As the Table 32 had shown, the fairs that will be attending take place during September, October, November and January. To be more exact, the following Table 33 was created.

Table 33: Travel budget

Fair	Place	Month	Number of Days	Cost (€)
Brinde	Porto, Portugal	September	4	416
SalzburgerSpielemesse + Modellbauwelt	Salzburg, Austria	October	3	312
Interpädagogica	Vienna, Austria	November	3	728
SüddeutscheSpielemesse	Stuttgart, Germany		4	
Lipper Modellbautage	BadSalzuflen, Germany	January	3	944
Spielwarenmesse	Nuremberg, Germany		6	
				TOTAL: 2400 €

Is estimated that every day we will spend approximately 104 € taking into account the budget that we have. This way, we will spend 2400 € in our travel budget. Also is necessary to consider that be present in the fairs have a price, it depends on where is the fair and how much space we need.

We should keep reminding that toy business is seasonal and the most part of the sales are done in Christmas. Therefore, the Marketing Expense Budget will be also seasonal. Spending will be done during the seven first months. This way, from February to the June 2015, we will work in our next toy. All spending are detailed in Table 34.

Table 34: Marketing expense budget

Marketing expense Budget (€)													
Type of promotion	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	TOTAL
Leaflet	400	0	0	0	0	0	0	0	0	0	0	0	400
Posters	0	300	0	0	0	0	0	0	0	0	0	0	300
Video	0	300	0	0	0	0	0	0	0	0	0	0	300
School demonstrations	0	0	100	100	100	100	0	0	0	0	0	0	400
Travel	0	0	416	312	728	0	944	0	0	0	0	0	2400
Trade stand	0	0	180	180	180	180	180	0	0	0	0	0	900
Unexpected cost	300	0	0	0	0	0	0	0	0	0	0	0	300
TOTAL	**700**	**600**	**696**	**592**	**1008**	**280**	**1124**	**0**	**0**	**0**	**0**	**0**	**5000**

4.10 Controls

The macro environment and micro environment are continuously changing. We must be aware of the economic and political changes of the marketing environment. Constantly, competition studies must be done, and it is also important to follow all the new toy companies that come into the market after us.

The toy industry is very innovative, and new toys are launched into the market every year. It is necessary to be attentive to the technology progress and the trends in the toy's world.

To keep track the marketing changes, customer feedbacks will be developed. The customers can give their opinions through polls and surveys. Social networks can be very useful to reach more people. The customer's feedbacks are interesting to get new ideas for our products.

4.11 Conclusion

To obtain successful results the marketing plan is crucial. Segmentation and Positioning and a well-developed Marketing Mix are necessary to achieve our target. Also the survey that was done has helped us in making decisions. Toy market is a competitive market with lots of strong toy companies. But we should take advantage of the opportunities that the toys market offers. As the market analysis had showed, out target market will be Europe, specifically we will start in Germany.

"Bro-Fish" will be a construction kit targeted to kids of an age range between eight and twelve years. The main difference from the competition is the high educational value that toy has, offering good quality and good value. In addition to teaching in three different fields (mechanics, robotics and programming), our toy will have customizable parts (tail, fins and programming packs) to always continue learning. Another factor that makes the difference from the competition is the wide range of services that our brand offers. Like the online technical assistance will be launch at the same time as the toy, the "Eco-friendly Plan", the "Special Teaching Packs" and the "Bro-Fish" Contests. These services will foment the customer's loyalty but also are a great tool to make promotion.

Finally, during this year, we will focus on the "Bro-Fish" promotion. Our toy will be present in all the toy fairs that will take place in Germany. During the second part of the year, we want to develop a new toy. One toy per year is part of our goals settings. High educational but fun toys will be the target. To make this possible, we have to know always which are the toys that parents and kids want.

5. ECO-EFFICIENCY MEASURES FOR SUSTAINABILITY

5.1 Introduction

Sustainable development is about the long-term conservation of the water, earth and ecosystem productivity and reduces negative impacts on the environment and human health. There are three different dimensions:

- Social sustainability, which is about building a long-term stable and dynamic society where basic human needs are met.
- Economic sustainability, which is about conserving human and material resources in the long term.
- Ecological sustainability, it could mean that economic growth must not be at the cost of a segregated and unequal society and a degraded environment. Society should aligned with the environment and human health can tolerate and which we term investing in these resources.

Already from the beginning of this project we had to keep sustainability engineering in the back of our minds because our toy is going to operate in water and is made for kids.

5.2 Environmental Dimension

Environmental sustainability involves making decisions and taking actions that are in the interests of protecting the natural world, with particular emphasis on preserving the capability of the environment to support human life. It is an important topic at the present time, as people are realising the full impact that businesses and individuals can have on the environment [**62**].

In "Bro-Fish" project, we are not going to create components ourselves and make suitable material choices. Our suppliers will be mostly local suppliers. Thus, the energy wasted in the transport of the pieces is less. In this section we will list the different solutions for our "Swimming Robot" about which materials and general aspects for developing our prototype:

- The hull: In our first prototype we are going to use PVC plastic pipe because it is easy to use and cheap for the first tests and the first time to build the prototype. In a remote future, for build serial productions we want to use a different material which is more sustainable and less dangers for the environment, such as Acrylic / Poly Methyl Methacrylate (PMMA).

- Electrical components: When we chose our electrical components we needed to keep several things in mind. The power usage needed to be as low as possible for our fish, all the components has to suit all the different requirements and movements, the weight needed to be calculate to make the fish to be in the perfect level in the water, etc. For the sustainability it was an important factor that we are able to recycle the electrical components properly because they contains heavy metals and other toxic materials.
- Batteries: Batteries can be divided into single use batteries and those that can be recharged. Batteries that are hazardous to the environment exist in both groups. This means that there is mercury, cadmium or lead in them. Mercury is often found in button cell batteries and cadmium is present mainly in rechargeable batteries. Rechargeable batteries are easier to recycle that the alkaline ones. And, they can be recharged and reused numerous times and this contributes less waste to landfills [**63**]. That's way we decide to use rechargeable Lead Acid Battery.

As it was said in the Marketing Plan, an "Eco-friendly plan" will be developed. This plan consists in encourage our clients to return the toy to the toys shops once the toy's life is over. This way, the pollution will be reduced and maybe any piece can be reused.

Energy efficiency is "using less energy to provide de same service" [**64**]. "Bro-Fish" is a biologically inspired swimming robot and we decided to develop the fish-like a movement because is an efficient way of swimming. Therefore, assuming that the robot will swim more efficiently in its final product stage, less energy will be needed.

It is necessary to take care in the material and manufacturing process control. The first step, is to try to improve the final prototype as well as possible. We have to study if all the pieces are necessary, which pieces can be replaced for others more efficient and what is the best way to get these pieces without damaging the environment. We will try to produce the minimum amount of waste. The waste produced must be separated and treated carefully.

5.3 Economical Dimension

Economical sustainability is the use of various strategies for employing existing resources optimally so that a responsible and beneficial balance can be achieved over the longer term. Economic sustainability involves using the assorted assets of the company efficiently to allow it to continue functioning profitably over time [**65**].

We want that consumers can identify our toys for the features that they have, but also, for the high environmentally friendly value that our company has. “Bro-Fish” is a toy for kids. In each toy of our future product line-up, kids can find an environmental leaflet. For example, in the case of “Swimming Robot”, kids will find a leaflet called “Why are our oceans important?” the content of the leaflet will include the main problems of the ocean, what kids can do to contribute to reduce the pollution of the oceans and also, a password to participate in a “Environmental Contest”.

Before every Christmas season, we will develop a charitable event. It will take place in the strategic sales points of our products. We want to encourage people to donate their old “Bro-Fish” to families that have insufficient financial resources. This way, the life of our toy will be longer and it is also good for the environment because it reduces waste production.

Other important parts are our employees. Specific environmental training programs will be developed to make our employees aware of how important the environment is for the company and everybody in the world. Also, we will be always available to hear proposals from our employees. Sometimes, small things, like an easier way to separate the waste, can make work more efficient.

5.4 Social Dimension

Social sustainability can be defined as “the ability of a community to develop processes and structures which not only meet the needs of its current members but also support the ability of future generations to maintain a healthy community” [**66**].

The Leadership in Energy and Environmental Design (LEED) will certificate our toy factory. LEED is a nationally accepted organization for design, operation and construction of high performance green buildings. This ensures the buildings are environmentally compatible, provide a healthy work environment and are profitable [**67**].

This also means that employers will be more confortable in their work environment. Another key point is the worker´s health and safety. Employees must feel safe at work. Factory safety courses will be developed. Of course, every worker will have his own safety material and a specific safety plan for our factory will be done including ergonomics advices. Besides the safety, there are more things to take into account for the employer’s healthcare and working conditions. The communication in our company is important. The employers have to feel invited to express what they want, and they have to feel that their opinions are useful for a successful operation of the company. The wages for workers will be determined fairly. Also, other advantages to reward workers will be developed. We can partner with companies to provide benefits like special prices in shops or holidays to our workers.

Motivation is part of our company´s strategy. We encourage our employers to improve their technical skills and attitudes. If they want to study more, the company will give them all possible facilities. If there are studies useful for our company, we will try to help our employers with the studies´ cost.

Our success depends on customer loyalty. First of all, we need to think about the safety of our customers, in our case, the kids, their healthy and security is always the top priority for our company. In our toy, we will use materials that are not dangerous and do not contain any sharp edges, which could harm the children. This is also important for all the services that we have developed in the Marketing Plan. These services make the clients loyal and satisfied.

5.5 Life-Cycle Analysis

Life-Cycle Analysis is a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle [**68**]. The life cycle analysis is a great tool that can help to understand the environmental impacts associated with products, processes, and activities.

5.5.1 Material Processing and Assembling

As was exposed in the chapter 5.2, we will buy the pieces from suppliers. We will choose our suppliers consciously. If some of the suppliers are using recycled-materials we will work with them. We are going to work with local suppliers. That means, the costs for transportation will be lower and the logistic and environmental impact as well.

5.5.2 Product Use

"Bro-Fish" is an educational construction toy that is customizable. Different parts of the robot, like the tail, the fins and the ballast of the fish, can be modified. This means that kids can still learn once the toy is completely assembled. Also, we will develop special packs with different levels of programming that will be sold separately. These features make our robot a toy with a longer use-life and less waste will be produced.

5.5.3 End of Life

As was presented in the Marketing Plan, a “Technical assistance of the product will be launched. In the event that any piece breaks, the client can order just a specific piece. To make it easier, every piece will have a specific number code. All pieces will be available in the “Swimming Robot” webpage. When the product´s life is over, the consumers can give the old toys back to the stores. Our company is responsible for collecting these toys, a then, in the factory we can separate and treat carefully the wastes.

5.6 Critical Ocean Issues

Part of our motivation is helping to preserve biodiversity and find and use natural resources more sustainably. We are convinced that encouraging children to understand the critical ocean issues better, will help make the future society more aware about the importance of the environment. In this section, the critical ocean issues will be presented, the following information is from the National Geographic webpage [**69**]. This information will be the basis for the “Kids Environmental Leaflets” that will be created.

5.6.1 Climate Change Affects the Oceans

Climate change is because humans emit large amounts of greenhouse gases, particularly carbon dioxide. The emissions come from our burning of fossil fuels. In a hundred years, the average temperature on earth has risen between 1 and 6 degrees. Even now visible effects of climate change, especially in the oceans. The climate has always varied, and periods of warmer climate have alternated with colder periods. The big problem now is that change happens so quickly that the environment, plants and animals do not have time to adapt to the changes.

5.6.2 Contaminants

Contaminants are a collective name for many types of substances that are harmful to biological life. Heavy metals and organic pollutants are two different groups. Although, that most pollutants have fallen sharply since the 1970s, represents society's massive chemical use remains a threat to the Baltic Sea environment. The successful effort to reduce PCB and DDT, however, shows that it is possible to lift a poor environmental situation. The use of toxic chemicals in society must be radically reduced, ideally cease. Here the political decisions and process development in industry a crucial role in such a change to come about.

5.6.3 Overfishing

Ocean overfishing is simply the taking of wildlife from the sea at rates too high for fished species to replace themselves. The earliest overfishing occurred in the early 1800s when humans, seeking blubber for lamp oil, decimated the whale population. The fish species that are particularly affected by over-fishing is the slow growth and low productivity, often-predatory fish. The Swedish list of threatened species ("Red List") occupies 35 fish species, of which ten are cartilaginous fish (sharks and rays). The list also includes economically important species such as eel, dogfish, cod, haddock, and turbot.

5.6.4 Foreign Species

A couple of decades ago, interests in foreign species are not large. Occasional findings were regarded at most as curiosities. They had not yet realized the extent of the effects that introduced species can bring. Over the last ten years the interest risen properly. A foreign species is a plant, an animal, a fungus or a microorganism with the help of humans has spread outside of its natural range. This may have been quite deliberately or accidentally.

A species that lives in harmony with nature in their home region could cause confusion into a new environment that may lack the usual inhibitions. Some species may have a profound impact on their new environment, and there are several documented "disasters" with foreign species. The removal of foreign species that have established themselves is almost impossible. One should therefore restrict the introduction of new species, especially if they know that they are causing problems elsewhere in the world.

5.6.5 Endangered Species

Life has existed on Earth for three and a half billion years. Throughout this time, changes in species composition occurred. Species have become extinct as a result of naturally induced changes in climate and conditions of life, and new, better-adapted species have evolved from earlier forms. During the Earth's geological history extinction waves when several species disappeared in a relatively short period of time (measured in a biological time scale) occurred repeatedly.

The wave of extinction of species had occurred in the last century, however, differs from the preceding chiefly by the number of vanished species per unit time is now higher than ever before in the biological history of life.

5.6.6 Dumping of Waste

The sea has long been regarded as infinite and therefore as a convenient place to dump all sorts of human waste. Earlier in human history, marine ecosystems could manage to break down a lot of organic waste so that the impact was probably negligible, except for the shallow bays and coastal areas. Unfortunately, this it not the way it is anymore nowadays.

5.6.7 Garbage

There are many different kinds of garbage; plastic package, cardboard boxes, abandoned fishing nets, rope, cans and bottles. Most of the garbage comes from ships. The crew simply throw their waste into the water. Even storms and floods can bring trash from beaches and towns into the sea.

A large part of the rubbish is plastic. From ships are dumped annually more than6.5 million tons of plastic in the ocean, which very slowly broken down. A plastic cup can persist for 100 years.

The garbage does not just look nasty. It also kills. Each year, drowning or damaged thousands of seabirds, fish and mammals because they are stuck in fishing nets or packaging. Others starve after they have swallowed plastic bullets that cause them to feel satiated and then they do not eat properly.

5.7 Conclusion

The importance of sustainability is increasing every day for companies. It is good for the environment and also helps companies to be profitable. Investing in sustainability allows companies to reduce long-term costs. Throughout this chapter it was explained that it also our factory and our employers are important for the environment. Also, it was presented critical ocean issues. Garbage, overfishing etc. are destroying the oceans. The largest living space on earth is fastly deteriorating.“Bro-Fish” is a toy that can help to awaken children´s awareness about the oceans problems. That is why our goal is to create a product that can make children think about how important the environment is for humans.

6. ETHICAL AND DEONTOLOGICAL CONCERNS

6.1 Introduction

For this project ethics and deontology have to be considered for every decision made. This will help us to create and place a successful product and brand on the market. This chapter will analyse five main ethical and deontological concerns and demonstrate how we apply them to our project. They are ethical issues on engineering in general, sales and marketing, academic issues, environmental concerns and liability.

6.2 Engineering Ethics

Every company and organization should have an individually defined code of ethics that members have to comply with. The specified rules may vary depending on the engineering discipline. For this multidisciplinary project only universal engineering ethics standards will be specifically addressed.

Therefore, a framework by the Royal Academy of Engineering and the Engineering Council of the United Kingdom is adopted, proposing the following fundamental ethical principles [**70**]:

- Accuracy and Rigour
- Honesty and Integrity
- Respect for Life, Law and the Public Good
- Responsible Leadership: Listening and Informing.

The team and its members try to aspire these standards in working habits and relationships. These aspects will also be predominant for the ideas evolved in the following sections 6.3 to 6.6, but some practical applications will be highlighted here:

- The product is designed to be safe for the user during construction and operation to hold paramount safety and health of the public. Therefore a user´s manual will be supplied and all possible efforts are made to identify, evaluate, quantify and reduce potential risks.

- Where problems exceed the team´s current competence, experts such as supervisors are consulted to eliminate uncertainties.

- All relationships are to be cherished with openness, fairness and honesty. If, despite all efforts, expectations cannot be met, a satisfactory solution has to be found in collaboration with all parties involved.

6.3 Sales and Marketing Ethics

Concerning marketing issues we are aware that our value proposition needs to be solid with the product. We cannot establish benefits that we are not sure about and thus mislead customers. Furthermore the future price of the product should reflect its true value and also costs for usage and maintenance of the product should be fully presented to ensure that each consumer is aware of possible expenses. These documents will be elaborated in a later stage of the project, but not within the EPS project phase.

6.4 Academic Ethics

It is our obligation to state the truth in all the deliverables and base conclusions on solid facts only. We have to mark cited sections and mention every source used. We should express ourselves clearly to prevent miscommunication. That includes explaining points plainly and justifying every conclusion precisely. An academic ethic issue is also to meet our professors and their work with respect, for instance by taking part in their classes and being well prepared for meetings.

6.5 Environmental Ethics

Environmental issues have to be considered during the entire product lifecycle. That is the production process, its lifetime and recycling (5. Eco-efficiency Measures for Sustainability). We try to minimize the environmental impact of the final product by choosing non-toxic substances, recyclable materials, and reusable components. Based on the prototype design, which is mainly focused on functionalities, more effort will be put into choosing the individual components of the final product following the above stated principles. An especially sensitive component is the battery that may not get in touch with the surrounding water. We take extensive care to prevent any leaking of toxic substances. Also, we are aware that moving parts of the swimming robot and sharp edges may harm playing children and the environment and try to keep their impact as low as possible.

6.6 Liability

Lastly, we have to be aware of our responsibility towards supervisors, clients, future customers and the law. If any error occurs, either unintentionally or on purpose, we have to bear the consequences. To minimize the probability for that to happen we should gather information about requirements and expectations towards us and in return clearly communicate duties and rights to any other party we are interacting with(3.10 Stakeholders Management). The following aspects have to be considered:

- While developing our project we have to comply with intellectual property law related to our product. We need to be aware of existing copyrights, trademarks and patents and must not infringe these. The name of our product is going to be "Bro-Fish" (4. Marketing Plan). The availability was checked on the website of the German Patent and Trademark Office (www.dpma.de) for this is going to be the first target market of our product. We intend to register a trademark for our product´s name and logo, which we originally created, there.

- We also need to be prepared being confronted by unsatisfied customers. Reasonable complaints have to be dealt with in an appropriate way. A good way to prevent unpleasant situations is defining terms of warranty in order to determine rights of clients and duties towards them beforehand. This is planned to be done after finishing the product design.

- To prevent or at least reduce any potential risks for safety and health while using the product, for instance being cut by sharp edges or swallowing small parts, we will have to elaborate and provide safety instructions in a user´s manual. Especially because our swimming robot is a toy for children we have to advice parents about potential risks and their duties to prevent them. We try to design the construction modules in a way that a minimum of harmful joining technologies (screw-driving, soldering) is required to assemble them.

- In addition, the legal framework provided by EU and local governments, which are directives about the usage of dangerous components or hazardous substances, have to be complied with.

6.7 Conclusion

The main ethical and deontological concerns related to our product were analysed, so that the team has now an idea about how to behave appropriately in the professional technological and marketing environment. We apply ethical thinking everywhere possible and if contradicting matters arise, we try to find the most appropriate compromise.

First of all, the product name “Bro-Fish” will be registered in the German Patent and Trademark Office. To minimize our concerns about ethics and deontology related to our consumers, in the future, the following documents have to be elaborated and provided along with the product: User´s manual including safety instructions, terms of warranty and a statement of usage and maintenance costs. Lastly, for the final product, more effort will be put on minimizing the environmental impact by choosing non-toxic substances, recyclable materials, and reusable components.

7. PROJECT DEVELOPMENT

7.1 Introduction

The objective of the project "Biologically inspired swimming robot" is to start developing an educational toy for children between eight and twelve years: a *construction kit for a swimming robot with biomimetic features*. The self-assembly product will provide an interactive opportunity to (1) learn about mechanical structures, (2) programming and (3) the physics of floating objects.

This chapter focuses on integrating the third feature into a swimming robot because physics of floating objects have only received little attention in the toy market so far. The goal is to develop a robot that can perform forward locomotion, has an easily controllable heading direction in the horizontal and vertical level and customizable features (Section 1.5).

Based on the knowledge obtained through state-of-the-art studies (Chapter 2), the development of a suitable architecture for the swimming robot will be presented in the following. Afterwards, the prototype´s required components, electronic functionalities and implementation processes will be explained and experimentally evaluated.

7.2 Architecture

The goal of this section is to find an architecture for the biologically inspired swimming robot that meets the initially set requirements (Section 1.5). Therefore, it needs to be defined at first, how many actuated segments and fins propel and steer the robot. While developing the mechanical structure it has to be kept in mind that only motors will actuate the robot´s body, as considered to be a more suitable solution for children to play with (Section 2.3.2).

7.2.1 First Design Approach

The motivation for the first architectural approach was *obtaining little mechanical complexity and keeping material costs low by using the least number of motors*. A segmented body structure, as to be seen in Figure 18, can propel and steer the robotic fish(Table 3: Robot no. 2). The segments are actuated by one servomotor each. An additional servomotor is located inside the hull, changing the fish´s barycenter and thus enabling steering in the vertical level (Table 5: Method no. 4). This method for ascending and descending has the advantage of mechanical simplicity and does not require another shell opening that could cause water leakage.

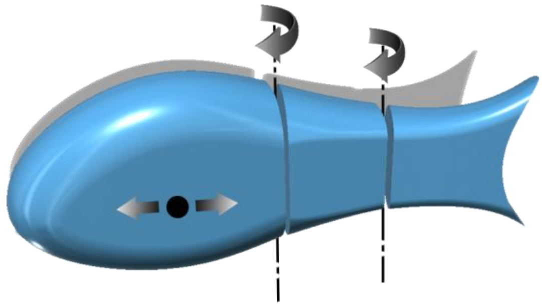


Figure 18: Design approach with few motors

This architectural design requires three motors only, but there is a major disadvantage to this approach – its complex controllability: The servomotors have to produce a travelling wave along the fish´s segments in order to generate propulsion. It might be a tough task for children to figure out how to alter parameters in order to achieve a desired response, for example steering left/right. It primarily requires programming skills instead of the interest in handling and experimenting with technical elements.

In respect to these thoughts, even though this architecture presumably requires the least number of moving components, it is not the most suitable solution for the proposed problem.

7.2.2 Second Design Approach

The second approach was aimed to create a *command-response-pattern easier to handle*. Therefore an architecture closely related to the existing prototype (Section 2.3.1) was adopted: The robot has one back fin and two pectoral fins at the side of the body (Figure 19). Unlike the existing robot, not the pectoral fins but the back fin is used for propulsion - an approach more similar to the natural locomotion of fish (Section 2.2).

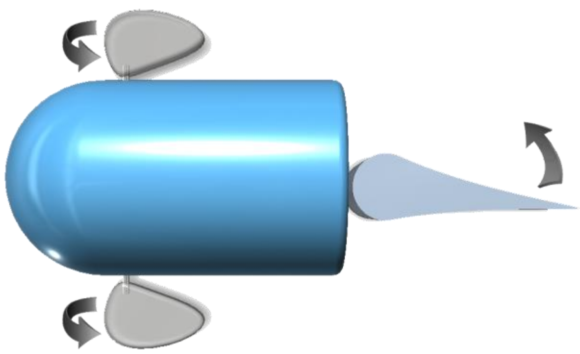
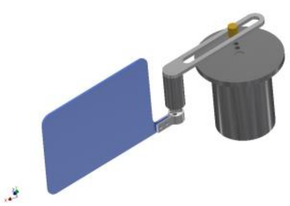
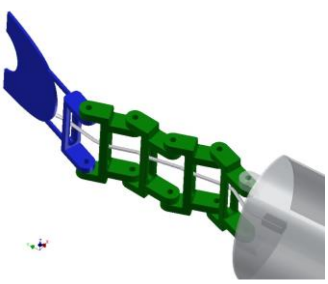


Figure 19: Design approach with simple controllability

In order to propel the robot with an oscillating back fin, higher frequency and torque than in the existing prototype have to be applied. It was found that a servomotor is at risk to break easily due to the rapid changes of direction (Section 2.7). For this reason it is not suitable for this application. A longer lasting solution is to transfer the continuous rotation of a DC motor into a swinging tail movement.

The following Table 35 displays the scope of development aiming to find the best suitable mechanism that transfers rotational into swinging motion. With each step the disadvantages of the previous idea are improved while trying to preserve the advantages.

Table 35: Scope of development for transferring rotational into swinging motion

SKETCH	DESCRIPTION	ADVANTAGES	DISADVANTAGES
	Bar attached to motor, second bar that can rotate around a fixed axis, connection of bars leads to oscillating motion of different amplitudes	- Constant angular velocity - Possibility to change amplitude of oscillation	- Space consumption inside hull - Hard to make watertight - Steering impossible
	Sliding connection of bar to motor, bar rotates around fixed axis	- Less space required - Easier to make watertight (shaft opening) - Possibility to change amplitude of oscillation	- Inconstant angular velocity (risk of swimming in circles) - Possible friction problems in connection point - Steering impossible
	Rotating shaft is bended, vertical slots in the segments provide enough space for the shaft to move freely, in horizontal level tail segments move in accordance to the shaft´s shape	- Undulation motion (higher energy efficiency possible than oscillation) - Motion is freely customizable by determining shape of shaft - Easy to make watertight - Little space consumption inside hull	- Possibly high friction and rattling at connection between shaft and segments - Steering impossible

The presented development process results in a mechanism that is actuated by a bended, continuously rotating shaft. Especially the freely adjustable shape of the shaft is considered a great opportunity for children to experience the effects of their modifications. Nevertheless, it has to be dealt with the two remaining disadvantages of this approach:

1. Concerning the risk of high friction and rattling, the prototype will reveal the feasibility of the construction for the final product.
2. Another consequence of replacing the servomotor by a continuously rotating DC motor is that left/right steering is not possible with the mechanism for propulsion. An alternative solution is to be found.

There are different solutions to enable steering in the horizontal level, as listed in Table 36. Every approach is individually analysed to assess advantages and disadvantages and to finally find the most suitable solution.

Table 36: Mechanisms to steer in horizontal level

STEERING MECHANISM	ADVANTAGES	DISADVANTAGES
ADJUST ANGLE OF THE OSCILLATING BACK FIN	-No additional fin required -Similar to fish locomotion	-Axes of flapping motion and adjustment of direction have to be aligned -Requires big shell opening → Hard to make watertight
ADD FIN AT BOTTOM	-High reliability (same mechanism is used for boats) -Easy command-response pattern -Small shaft opening, easy to make watertight	- Additional shaft opening in shell required
USE EXISTING PECTORAL FINS	- No additional components required (fin, actuator)	-Risk of rotational motion of entire robot around longitudinal axis -Steering by breaking leads to low energy efficiency

After evaluating all arguments it was decided to implement an *additional fin at the bottom of the robot* because it is a simple and reliable mechanism.

7.2.3 Final Architecture

Based on the ideas developed in the previous sections, the architecture of the biologically inspired robot was simulated using 3D design software. The final body architecture looks as displayed in Figure 20. A BCF propulsion-mechanism was adopted for the robot: along, agile tail with a fin at its end generates forward propulsion, a pair of pectoral fins located at the sides of the body can control the robot´s swimming depth and one at the bottom used for steering left/right. When turned perpendicular to fluid flow, the fins are also aimed to break the robot effectively. The developed architecture resembles a fish successfully and ensures steering with a command-response pattern that is easy to handle.

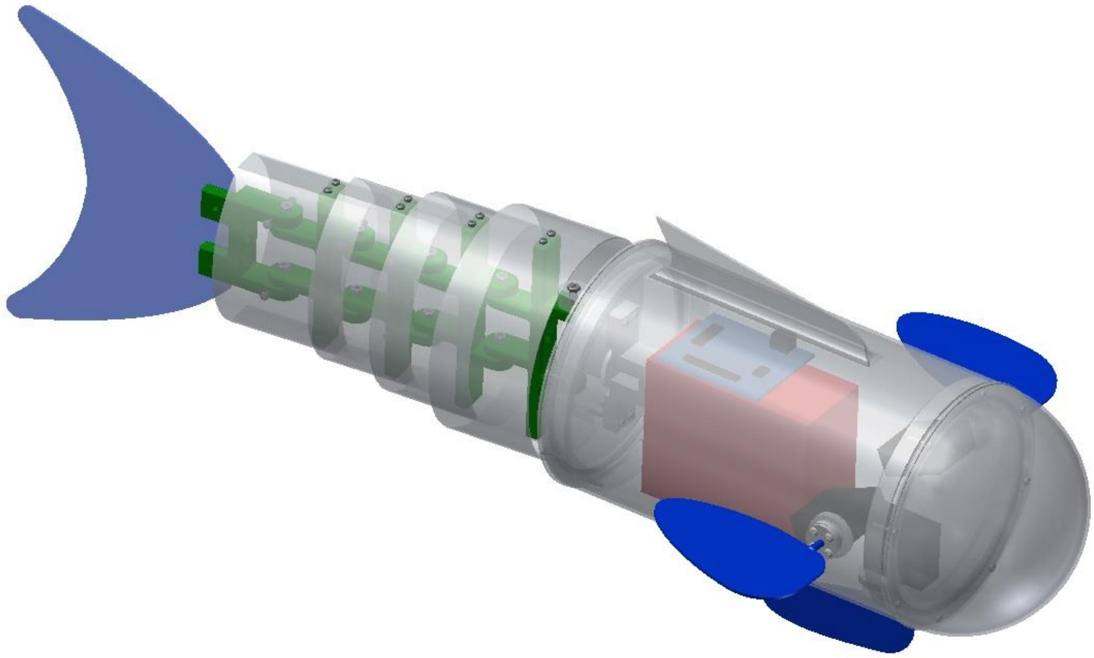


Figure 20: Final architecture of the swimming robot

The model in Figure 20 already contains conclusions of the discussion of individual components that is presented in the following Section 7.3.

7.3 Components

This section details the components used for the realization of a prototype, which is based on the architecture introduced in the previous section.

In the following, the robot´s body, tail mechanism, fins, motors, battery, control unit, ballast weights and waterproofing techniques are discussed and selected, resulting in the list of materials.

7.3.1 Hull

For the robot´s hull (also body or shell) the most suitable *shape*, *dimension* and *material* need to be selected. In this process, the following requirements have to be complied with:

- Enough space to house robot´s insides
- Waterproofing
- Suitable buoyancy[4] to balance out robot´s weight
- Minimum drag[5]
- Stability against rotation
- Little production costs
- Safe handling during assembly and playing

<u>Shape of the Hull</u>:

The selection of the hull´s shape is dependent on several aspects with varying relevance for the shape´s characteristics. They are *drag, stability, production costs and connectivity to adjacent parts*. The first decision made, was to use a round pipe as basis for the hull because the usage of this off-the-shelf product keeps costs low. Secondly, the question was raised which cross-sectional shape was the most suitable for the swimming robot. In Table 37, round and oval shapes are compared.

Table 37: Assessment of possible cross-sectional shapes for the hull

CROSS-SECTIONAL SHAPE	ADVANTAGES	DISADVANTAGES
ROUND	- Off-the-shelf product, no deformation required - Possible to thread things onto its ends	- Little stability against rotation around longitudinal axis
OVAL	- Better stability against rotation	- High production costs: hard to squeeze pipe equally throughout its entire length - High accuracy required, sealing problems might occur at pipe´s interface with adjacent covers

Based on this analysis and considering the little time available for the prototype´s implementation, it was decided to keep the complexity low by buying a *round pipe* and

4 Buoyancy: Upward force exerted by a fluid in which a body is immersed; more information can be found in Section 7.3.7.

5 Drag: Fluid resistance caused by the robot´s locomotion through water.

leaving it like this. Stability problems can be solved by a low position of the center of gravity (Section 7.3.7) and an adequate number of static fins attached to the body (Section 7.3.4). For the final product this decision can be revised because mass-production will significantly reduce the expenses for manufacturing individual shapes.

In order to minimize the swimming robot´s drag the overall shape needs to resemble a streamline. A *spherical cape* will be attached to the pipe´s front. In the back, there will be a planar plate attached to the pipe, sealing its insides from water contact. More information on waterproofing details will be provided in Section 7.3.8. The realization of a smooth transition from the round hull to the tapered tail fin will be addressed throughout the tail development in section 7.3.3.

Dimensions of the Hull:

The hull´s dimensions are dependent on the *volume of the components that need to fit inside*. It should provide enough space for all parts and their interconnections, plus an *additional space to enable assembly* without damaging adjacent modules. On the other hand, the hull should not be immoderately oversized in respect to the requirement of making the robot dive under water: The *buoyant forces* are dependent on the amount of displaced water and thus on the volume of the object itself. Because the robot will be comparably light in relation to its displaced volume it was roughly calculated that mass will have to be added in order to achieve static equilibrium and enable diving – the larger the hull it gets the more weight has to be added. This correlation in particular will be dealt with in section 7.3.8.

The hull´s diameter for the prototype needs to be selected according to the available pipe sizes, which are low-cost off-the-shelf products.

All components that are located inside the hull (and will be discussed individually in the following sections) were animated and localized using a 3D-Design program (Inventor). Thus, it was detected that the most suitable dimensions for the prototype´s hull are a *diameter of 16 cm* and a *length of approximately 25 cm*.

Materials of the Hull:

The hull is the robot´s shell that should not only seal off water, but also let it flow by with little friction. A durable material is required that is *impermeable and resistant to water* and has a *smooth surface*. In addition, it is good to incorporate *transparent* pieces into the shell of a construction toy and prototype to be able to see how the components work inside.

Because the final product is going to be a toy for children, it is also essential that the material is safe during assembly and playing. That means it must not release any *toxic substances* or *shatter* into sharp pieces when breaking.

Lastly, the material and processing *costs* have to be considered. The material should be workable for mounting framing, covers and other components to it.

In Table 38, two materials are inspected for their suitability to be installed into the robotic fish [**71**]:

Table 38: Assessment of suitable materials for the hull

MATERIAL	ADVANTAGES	DISADVANTAGES
ACRYLIC / POLY METHYL METHACRYLATE (PMMA)	- Completely transparent - High impact resistance (if it breaks or get damaged it will not shatter) - Rigid plastic - Light weight - Mouldable into any desired shape - Can be sawed	- Transfers heat poorly - Combustible - Expensive
POLYVINYL CHLORIDE (PVC)	- Excellent durability and long-life expectancy - Highly resistant to degradation - Chemical stability - Light weight - Requires little to no maintenance - Low cost material	- Sensitive to UV and oxidative degradation - Not properly used it *may be hazardous to health* - Environmental effects

Weighing out all arguments for and against the considered materials, it was decided to use acrylic for the final product. Especially its characteristics, which ensure safer handling and the opportunity to see the insides of the robot during operation, were decisive reasons.

To keep costs for the prototype low, it was decided to use a PVC tube for the hull. Only the spherical head and the plane back cover are made of acrylic. This set up fulfills the requirements to conduct functionality tests with the prototype but is not adequate for the future product due to its toxicity.

7.3.2 Tail

The tail mechanism developed in section 7.2.2 is the key concept of this project. It is propelling the robot by performing an undulating motion, which is activated in an innovative way.

The tail consists of 5 structurally identical segments that vary in size and are connected with stainless steel bolts secured by self-tightening nuts, plus an additional tail fin (Figure 21). This configuration allows rotation around the vertical axis only. In the middle of each segment there is a hole through which a 2 mm shaft of spring steel is led, which rotates continuously.

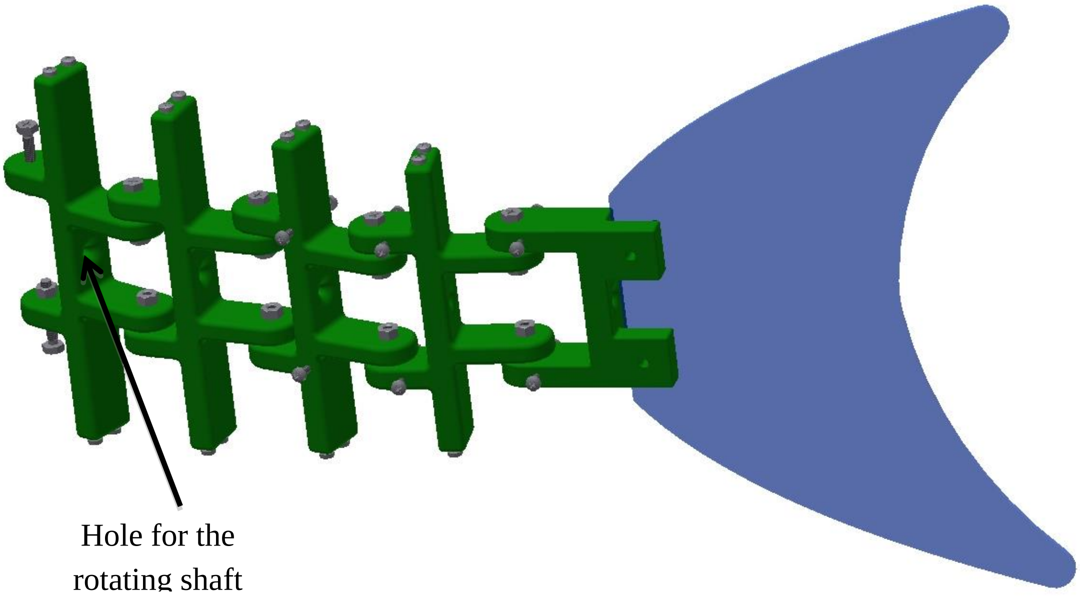


Figure 21: Tail Mechanism (displayed without shaft)

The shaft can be bended by the user into any desired shape. As it rotates, the tail segments move horizontally according to the shaft´s shape. Vertically, the tail segments are secured in their place, which is why the flexible shaft has to compensate arising forces by straightening. The tail mechanism provides the opportunity to freely modify its horizontal amplitudes of movement. Also, the entire mechanism can be attached to the body rotated by 90 °, so that the robot performs a movement rather similar to a whale or dolphin.

To realize a smooth transition from the round body of the robot to the thin tail fin, an oval cover is attached to each tail segment, decreasing in size as the end of the robot is approached and overlapping to prevent gaps in the surface. The covers are made from a thin, elastic plastic to make them easy to bend and secure in place. In Figure 22, there is the whole tail connected with bolts and with covers, two of which were removed to better present the connection between sections.

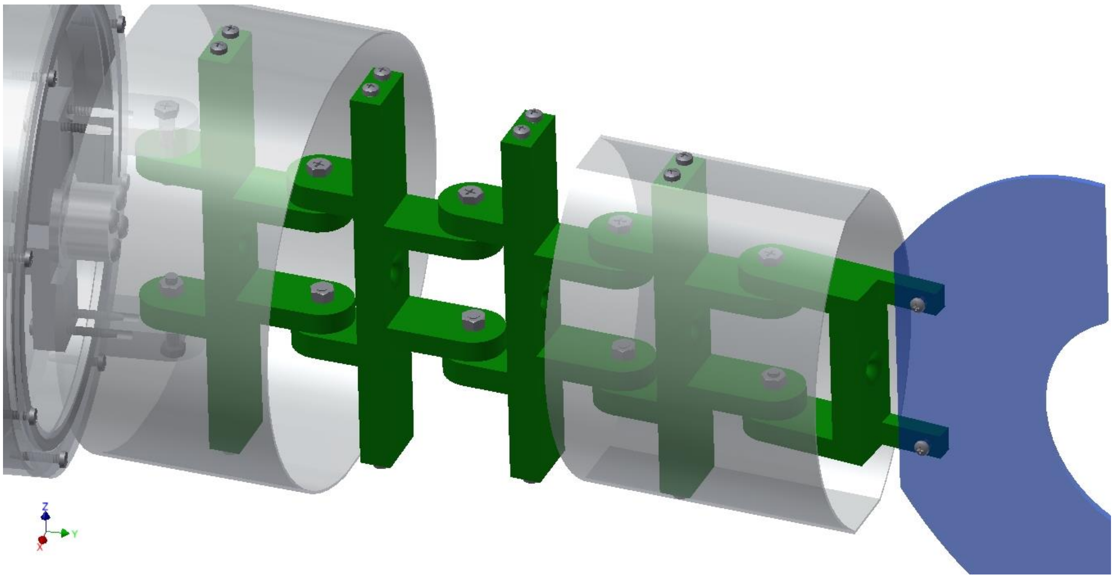


Figure 22: Designed tail with covers and fin, bolted and secured

The tail segments are printed by a 3D printer and consist of hard plastic. The tail fin is cut from a hard plastic plate. Different sizes and shapes can be tested.

3D printing is a new technology, which requires a special approach in 3D designing and taking into consideration that not all features are possible to print, like horizontal grooves in the parts. All our parts were consulted with an engineer in mechanics to eliminate our mistakes and correct parts before printing. Machining processes can improve the accuracy of the pieces.

The developed tail-mechanism is an innovative approach to generate propulsion. To reduce the possibility of failures the mechanism has been animated with 3D-design software, but functionality tests were required in order to analyse feasibility and efficiency (Section 7.6).

7.3.3 Fins

Fins influence the robot´s stability and heading direction, if attached in adequate spots along the hull. This is caused by two reasons: The fins (1) change the hull´s vertical surface area presented to the water and (2) can generate lift forces as the robot moves through the water (like wings of an airplane or the rudder of a boat). A suitable *number*, *position*, *shape* and *size* of fins and their *material* have to be detected. The fins are either statically attached to the hull or can rotate around an axis. In the second case, also the fin´s allowed *rotation angle* has to be determined.

Rotating fins:

As developed in section 7.2.1, the swimming robot requires the following moving fins, which are necessary for performing basic steering operations:

- Two pectoral fins on the sides of the hull for submergence and emersion of the robot in the water (steering in vertical level),
- One bottom fin for steering in the horizontal level.

The working principle of the steering fins is based on the generation of lift. As the robot moves through the water, the fluid flows past the robot´s surface and generates dynamic forces: Lift (perpendicular to oncoming flow direction) and induced drag (parallel to fluid flow) [**72**]. The amount of generated lift is dependent on the fluid´s velocity, the fin´s size, cross-sectional shape and angle of attack [**73**]. The hydrodynamic quality of a fin with a certain shape and size is measured by the lift-to-drag ratio, a higher ratio meaning that less thrust is required to generate sufficient lift. Analogous to the wings of airplanes, long narrow fins give the robot more stability, whereas short wider fins enable high maneuverability [**74**]. At this stage of development, the robot´s swimming behaviour cannot be predicted accurately, which is why the prototype´s first fin models are replications of the ones used for the modular robotic fish (Table 3: Robot no. 2).

The two pectoral fins are attached to the hull horizontally, each on one side. This way, they generate lift forces in the vertical direction only, which ensures high energy-efficiency. When turned more or less perpendicular to fluid flow, the fins can also be used for effective breaks. The position of the fins should be far away from the rotational transverse axis in order to generate a great momentum and fast turning. That is why the pectoral fins were placed the furthest to the front of the robot as possible, which is the same way fish work [**75**].

The steering device in the horizontal level is the bottom fin that functions like a rudder of a boat. In contrast to the rudder-mechanism, the robot´s architecture does not allow installing the bottom fin at the rear of the body. That is why it will be experimentally tested how well a fin located in front of the vertical rotational axis is capable of steering the robot left/right.

All fins will be cut out from stiff plastic material. We will model the fins in couple of configurations and test different sizes and shapes to finally choose the best one. Figure 23 shows the exemplary design of the fins, while Figure 24 shows the layout of the fins on the hull.

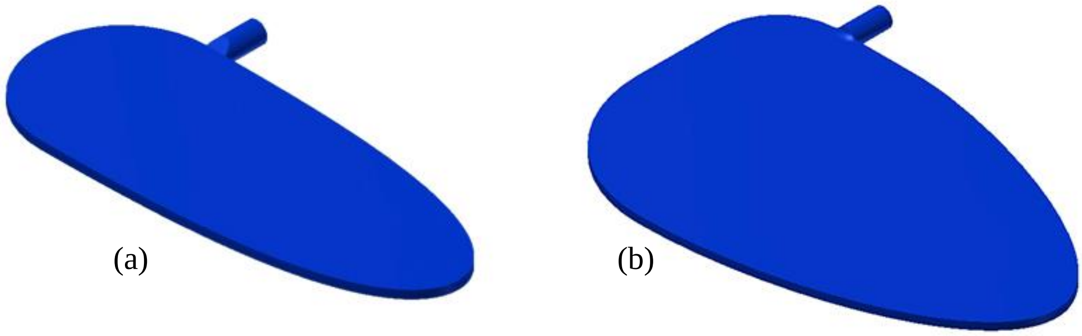


Figure 23: First models of (a) bottom fin and (b) pectoral fin

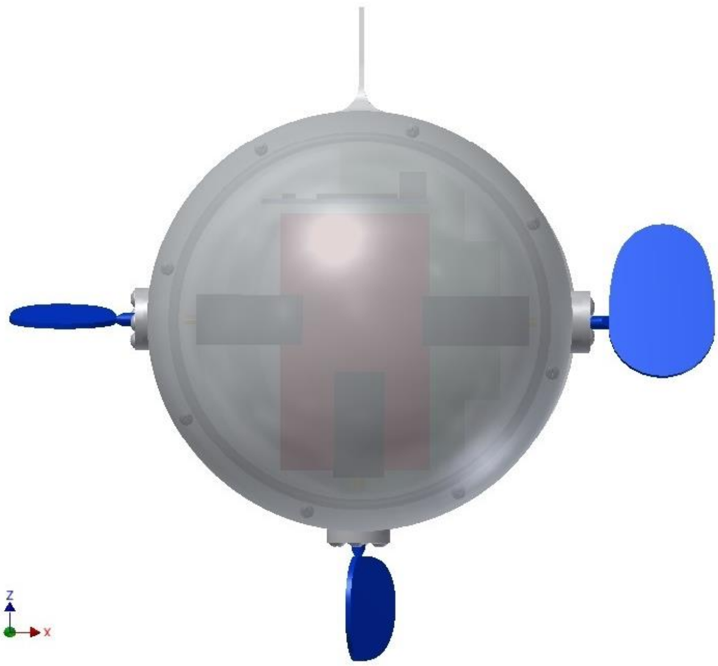


Figure 24: Configuration of fins (front view of robot)

<u>Static fins</u>:

Additionally, static fins can be added on the sides, top and/or bottom of the hull to increase the vertical surface area presented to the water. This stabilizes the robot against rotation around the longitudinal axis and prevents big deviations from the intended course of the robot.

7.3.4 Motors

In our prototype we use two kinds of motors:

- DC motor – which is characterised by maintaining rotations in one direction with variable rotations per minute (rpm), in this case up to 100 rpm. Our motor can produce a torque of 5 kg-cm, which should be more than enough to rotate the tail shaft and propel the prototype forward.
- Servo motors – very easy to control, with possibility to make measurable rotations (e.g. clockwise rotation by 10 ° angle). Those motors will be used to steer our prototype left, right, up and down in the water. Every motor will be connected to one fin and will be separately controlled by the controller.

We will have a separate servo motor for every steering fin. That will reduce the complexity of the design inside the hull and increase the accuracy of steering. Using one servo motor for steering of pectoral fins (responsible for up and down movement) would require a set of cranks and linking rods inside the hull which will complicate the design. Using two motors is not much more expensive but saves us a lot of time and designing problems.

7.3.5 Battery

For our prototype we have chosen a 6 V lead acid battery with 9 Ah capacity. Lead acid batteries are very heavy which is very good for us due to big weight required to pull the prototype under water. That will reduce the amount of additional weight we will need to put inside the hull. Next factor is size of the battery that we have chosen, it is relatively big in comparison to alternatives but will fit inside the body of our robot without problems. Also lead acid batteries are much cheaper than lithium batteries which is good to help keep founds of our project in the given limit.

To know the total power consumption we needed to calculate the current and power consumption of each component. Sometimes these two value were given in the datasheet for the devices, but mostly only one, but the other one is easily calculate with the following formula:

$$P = (I * U)/1000$$

P - power [W]
I - current [mA]
U - voltage [V]

In Table 39, the result for all the devices that need power is listed and their consumption.

Table 39: Power consumption of robot´s components

DEVICE	OPERATING VOLTAGE (V)	CURRENT (MA)	POWER (W)
ARDUINO UNO R3	6	16.43	0.10
MICRO METAL GEAR MOTOR HP POL-994	6	1600.00	9.60
SERVO MOTOR HITEC- HS 422	6	520.00	3.12
TOTAL FOR ALL DEVICES		**2136.43**	**12.82**

From these calculations we know that the total power consumption is 12.82 W, and with our battery of 6 V and 9 Ah we can perform the following calculations:

Multiply 6 V with 9 Ah gives us 54 Wh, and by dividing the Watt-hours with power consumption of our prototype:

$$\frac{54\ \mathrm{Wh}}{12.82\ \mathrm{mA}} = 4.21\ \mathrm{h}$$

As result, we can operate our fish for at least 4.21 h underwater until the battery has to be recharged, under the condition that the DC-motor and the servo motor will operate at full speed all the time. In reality, the battery time will be longer because the DC-motor will only about 1/3 of the speed and the servo motors only need the full amount of power when they move position with that in our mind we know that our prototype will operate a lot longer than 4.21 h.

7.3.6 Control Unit

To control our robot we chose an Arduino uno-R3 with the ATmega328 microcontroller. Arduino is often used in different robot projects, because it works very well with many other components and there is much information about programming the Arduino and connecting it to different motors and steering devices. We chose the Arduino uno-R3 because it has enough inputs and outputs for our project, and the control unit was also cheaper than many other similar microcontrollers.

7.3.7 Ballast Weights

The swimming robot shall be able to dive under water and stay at a particular water depth without spending much energy. In order to comply with this requirement, a method employed by fishes is copied, which is achieving a state of weightlessness, also called neutral buoyancy or static equilibrium (Section 2.2). Table 40 explains the correlation between an object´s volume and its required mass to float in water.

Table 40: Stepwise explanation for the required mass of a floating object

DESCRIPTION	FORMULA
The buoyant force of an immersed object is equal to the weight of its displaced water.	$F_{buoy} = V_{displ.water} * \rho_{water} * g$
If the object is fully immersed, its volume is equal to the displaced water´s volume.	$V_{object} = V_{displ.water}$
The opposing downward force is a result of the object´s mass in the earth´s gravitational field.	$F_{down} = m_{object} * g$
To balance a floating object, the up- and downward forces have to be in static equilibrium.	$F_{down} = F_{buoy}$
That makes the required mass of the object dependent on its volume.	$\mathbf{m_{object} = V_{object} * \rho_{water}}$

Concluding from Table 40, the robot´s volume has to be calculated in order to estimate its weight, which is required to achieve neutral buoyancy. For this rough estimation only the volume of the pipe and the spherical cap will be taken into account omitting the tail and fins.

Table 41: Calculation of robot´s required mass

DIMENSION	FORMULA		VALUE
Density of water:	ρ_{water}		$= 1000\,kg/m^3$
Diameter of pipe:	d		$= 0.16\,m$
Length of pipe (expected):	l		$= 0.25\,m$
Volume of pipe:	V_{pipe}	$= \pi * d^2/4 * l$	$= 0.00503\,m^3$
Volume of spherical cap:	V_{cap}	$= \pi * d^3/12$	$= 0.00107\,m^3$
Total Volume of robot	V_{robot}	$= V_{pipe} + V_{cap}$	$= 0.00610\,m^3$
Required mass of robot:	$\mathbf{m_{robot}}$	$\mathbf{= V_{robot} * \rho_{water}}$	$\mathbf{= 6.10\,kg}$

A rough estimate of the robot´s total mass of single components reveals that motors and battery together weigh only 1.5 kg. It is noticeable that the required mass of the robot highly exceeds this value. That is why *ballast weights have to be incorporated* into the robot – as opposed to fishes that evolved mechanisms to reduce their body´s density (Section 2.2). This contrast is caused by the robot´s high amount of void spaces that can be traced back to inevitable gaps between assembled components of different shapes and deliberately added free spaces for enabling assembly (Section 7.3.1).

Adding the masses of hull, tail, fins and mechanical connectors to the robot´s total mass, a required ballast weight of not more than 4 kg is to be expected. The real required gain of weight has to be found out during the functionality tests with the prototype.

Considering the high amount of mass required, metal bars are used because of their high density and good availability. The immersion of the hull will be tested experimentally (Section 7.6) and extra weight will be added until the robot is fully immersed. The target is to remain a buoyant force that will bring the robot to the surface in case of losing control, which is small enough to make the robot dive under water using the pectoral fin´s lift forces.

The metal bars should be located in the bottom part of the robot to enhance its stability around the longitudinal axis. Also, the robot needs to be balanced around the transverse axis so that it floats horizontally in parking position. To change the amount and distribution of weights of the final robot toy will be another feature for children to experiment with.

7.3.8 Waterproofing

The biologically inspired swimming robot is aimed to operate underwater. Its delicate electronic components inside the robot´s body have to be sealed off from water. From the waterproofing methods analysed in section 2.5, we chose to use O-rings for this project in accordance to our supervisor´s advice.

The connection between pipe and plane back cover needs to be detachable to enable the robot´s assembly and later works on its insides. Therefore, a plastic ring is glued to the inside of the pipe. An O-ring is placed into the groove that is milled into the plastic ring. By tightening the plane back cover to the plastic ring with screws the O-ring is squeezed and thus seals off water.

To connect the servomotors with the fins on the robot´s outside, the shafts need to break through the shell. The shaft opening displayed as an exploded model in Figure 25 was developed. It consists of a machined aluminium rod, a detachable cap and an O-ring. The shaft (indicated by the symmetry line) is led through the O-ring, which is squeezed by tightening the screws on top and thus seals off water.

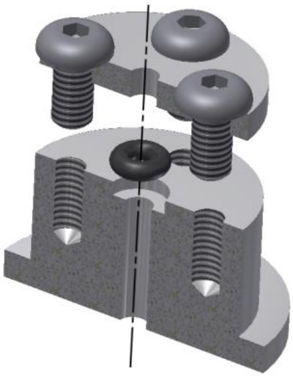


Figure 25: Cross-section of waterproof shaft opening

7.3.9 List of Material

To sum up the discussion about components in this section, the list of materials required for the prototype´s implementation is presented in Table 42.

Table 42: List of materials

COMPONENT	DESCRIPTION	STORE	PRICE
SERVO-MOTOR	Hitec- HS 422	inmotion	38.85 €
DC MOTOR	Micro metal gearmotor	inmotion	14.95 €
MOTORDRIVER SHIELD	Ardumoto	inmotion	19.90 €
BATTERY	PS - 682	mouser electronics	16.99 €
FUSE	Fuse 2 A	mouser electronics	2.38 €
FUSE HOLDER	Fuse holder	mouser electronics	0.95 €
DC PLUG	DC plug	mouser electronics	2.35 €
TERMINAL	Terminal red	newark	0.36 €
TERMINAL	Terminal blue	newark	0.78 €
REMOTE CONTROL BOX	Project case	sparkfun	9.95 €
CONTROL UNIT	Arduino Uno - R3	mouser electronics	19.61 €
SIGNAL CABLE	CABOJ45	Aqurio	7.00 €
RESISTOR	Resistor	inmotion	0.75 €
BUTTONS	Momentary push button	inmotion	1.60 €
PCB	PCB eurocard	Aqurio	2.50 €
POTENTIOMETER	Potentiometer 10 k linear	inmotion	0.95 €
TUBE (PVC)	Main body of robot	AKÍ	0.86 €
3-D PRINTING FILAMENT	Filament for printing plastic components		75.00 €
O-RINGS	watertight connection between body seal ring and circular plate	Vedantes to Porto	15.00 €
ALUMINUM ROD	2030 alloy, 2,8 kg/m	Lanema	30.00 €
DUCT TAPE	White duct tape 5m long	Leroy Merlin	9.49 €
TOTAL			270.22 €

7.4 Functionalities

7.4.1 Propulsive Structure

The employed structures to propel and steer the biologically inspired swimming robot are explained in section “7.2.3 Final Architecture”.

7.4.2 Electronic Circuit

In Figure 26, there is presented the components used for our swimming robot and the outside control and it gives an overview of how all connections are connected to the Arduino and also which parts that is used in the prototype. The main part is the Arduino with the motor shield Ardumoto attached on top which connects all the parts together. We used 3 servo motors with have power supply directly from the battery and the DC- motor is connected to the motor shield to easily change the speed of the engine. To control the prototype under water we have built an outside control box which is connected to the Arduino with a cable. The control box is built on a PCB with for momentary press button and a potentiometer to operate the movement of the swimming robot.

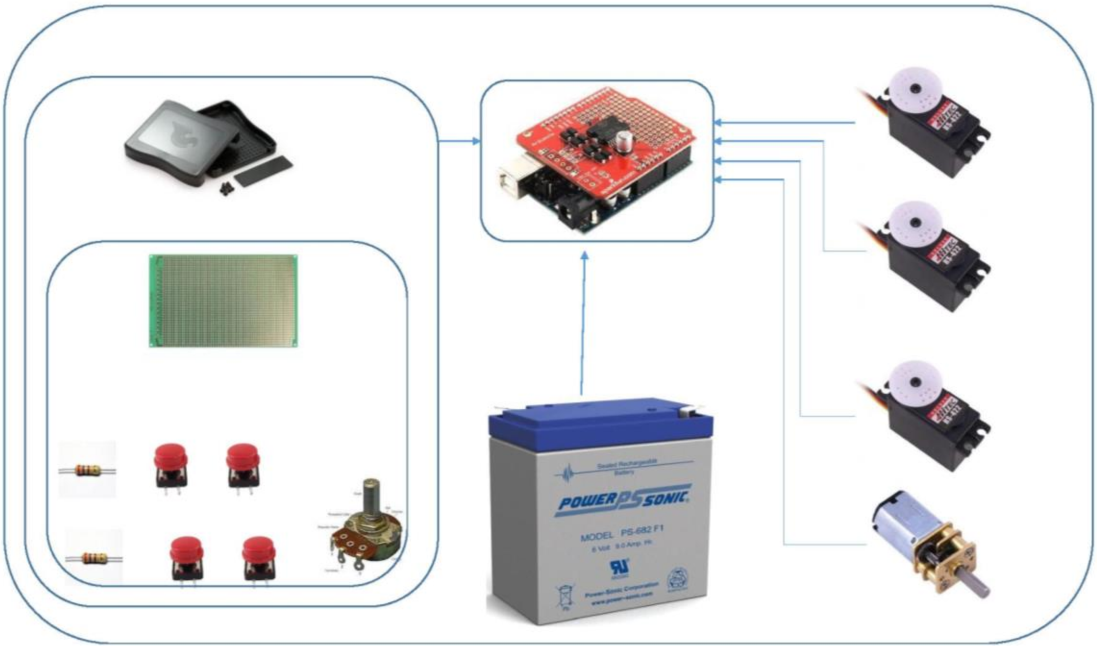


Figure 26: Overview of electrical components

<u>Simulation of the prototype:</u>

Before we got our parts we got informed about the program 123d circuits (Figure 27) where we drew the circuit, programmed the Arduino and simulated the wanted circuits, but in the program there weren't exactly the right components but similar for example we used a 9 V battery in the simulator but I reality we used a 6 V. It helped a lot to make the prototype in the simulator first because then we knew that the program will work.

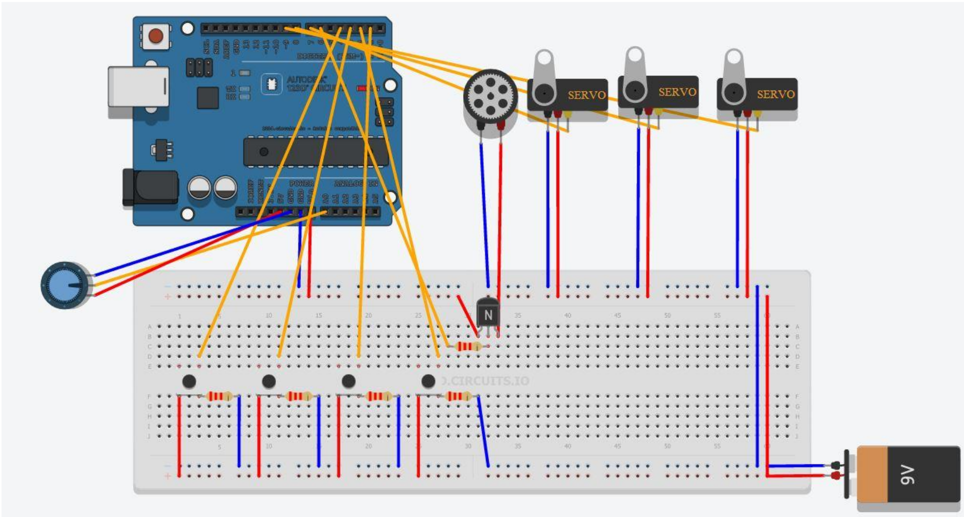


Figure 27: Simulation of electronic circuit

The movement of the fish tail will be driven by DC-motor that we will change the speed on using a potentiometer to the analogue input.

<u>Physical Connections</u>**:**

In Figure 28 is all the connections described in detail, which button or motor that is connected to which input and output.

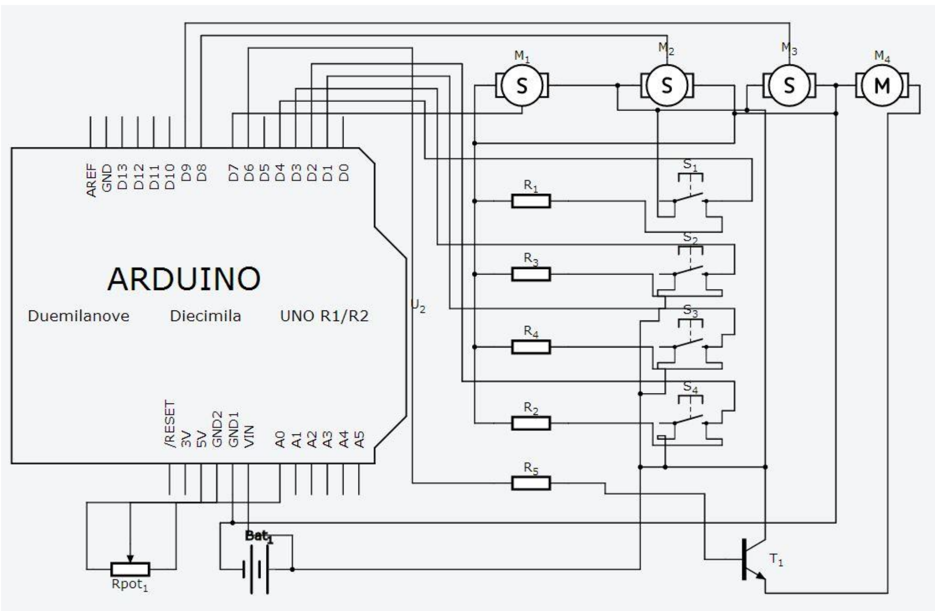


Figure 28: Detailed connections of electronic circuit

7.4.3 Programming

The Arduino in our prototype we programmed with the computer language C++ in the Arduino1.0.5-r2 software that it is possible to download from the Arduino home page. For the DC- motor we use Pulse-width modulation to control the speed. Pulse-width modulation is a modulation technique that controls the width of the pulse, formally the pulse duration, based on modulator signal information, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors, that makes it possible for the user to control the speed of the motor. For the servo motors we used the Arduino library “<servo.h>” that is included the software from the start, by using the library the microcontroller know how to operate the servo motors. The following Figure 29 a bit of the code for controlling of the DC-motor is presented, where it is displayed how to use Pulse-width modulation in a program.

```
    myservo3.writeMicroseconds(1500);

  }

  if (press4 == HIGH){
    myservo3.writeMicroseconds(500);
  delay(1000);
  } else {
    myservo3.writeMicroseconds(1500);

  }
  potentioValue = analogRead(0);
  //0 means Read Value from Analog A0
  potentioValue = map(potentioValue, 0,1023,0,255);
  //as we know LED's brightness ranges from 0 - 255
  analogWrite(3, potentioValue);
  //Show output at 9 pin according to potentio's value

}
```

Figure 29: Example of program and code

7.5 Tests and Results

A series of tests is required to experimentally evaluate if the robot is working as expected. The following tests have been performed.

7.5.1 Test of the Tail’s Motion (dry)

Test set-up: Tail segments and the back fin are put together by bolts and secured by self-securing nuts (Figure 30). The spring steel shaft is led through the segments and connected to the DC motor. The DC motor is connected to the control unit and activated by turning the potentiometer on the remote control. The test is conducted in dry condition outside the water.

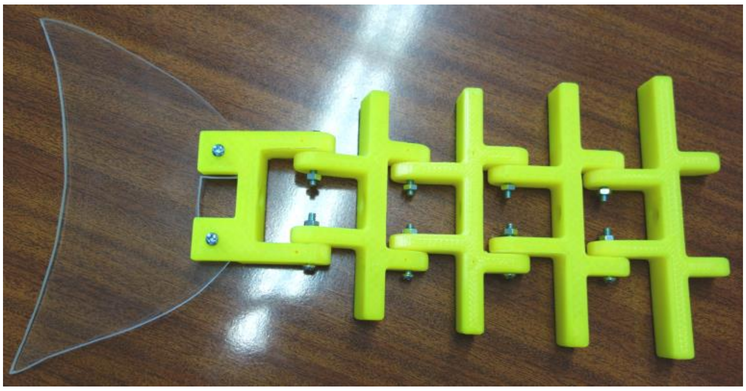


Figure 30: Assembled tail segments with back fin

Results: The tail moves as expected in dry condition. To improve the undulating movement of the tail, the shaft has been shortened so it does not connect with the last two tail segments anymore. Instead, these segments were activated by elastic bands connected to the last moving segments (Figure 31). Outside the water, this mechanism created the expected fish-like motion. Sometimes, the DC motor struggled to rotate the shaft when the tail's end oscillated in the opposite direction than the bended shaft. This problem could be reduced by not holding the tail horizontally but vertically so that the tail hung on its support. These problems might be solved when the mechanism operates in water because of the water's damping effect. By changing the shape of the spring steel shaft, different amplitudes could be performed. Also the amount of elastic bands on the last segments was varied.

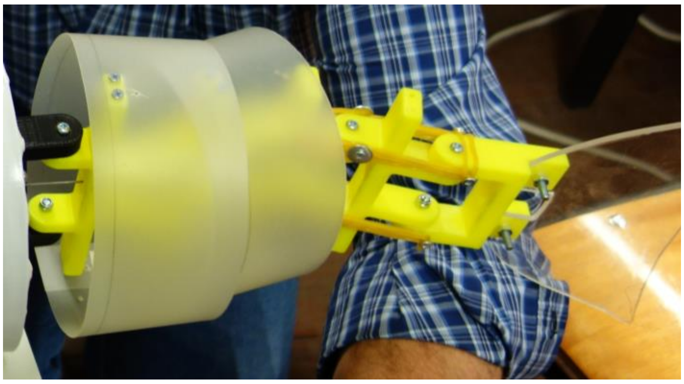


Figure 31: Tail with two covers and elastic bands

7.5.2 Test of Controlling the steering Fins

Test set-up: Both pectoral fins and the bottom fin are put together inside the hull. The servomotors are attached to the control unit and signals are given from the remote control by pressing "up" and "down" buttons for pectoral fins and "left" and "right" buttons for the bottom fin.

Results: The program works as expected. The fins' rotation angles were calibrated until they seemed suitable for steering the robot sufficiently without generating too much drag.

7.5.3 Waterproofing Tests

Test set-up for connection plastic ring/ plane cover: At first, the detachable connection between pipe and plane back cover, as explained in Subsection 7.3.8, was tested. The plastic ring is glued to the inside of the pipe's end with epoxy resin. The O-ring is put into the groove and the acrylic cover attached to the ring with eight screws. Water is poured into the pipe.

Results for connection plastic ring/ plane cover: Water is dripping out at a water column of about 5 cm inside the pipe, as to be seen in Figure 32.

Figure 32: Water dripping out of pipe with attached cover

Conclusion for connection plastic ring/ plane cover: The sealing mechanism cannot be applied to the prototype with this combination of materials. Two possible failure causes are assumed: The plastic ring is produced by a 3D printer and thus has an uneven surface. Even after treating the surface with sandpaper there remain small grooves through which water might slip. The second problem might be the high elasticity of the acrylic cover. When tightening the screws, the pressure is not spread evenly on the connection between cover and O-ring, but the cover deforms. This problem could be solved by using a stiffer cover and increasing the number of screws to fix it.

Test set-up for shaft opening: A shaft is led through the aluminium shaft opening, as explained in Subsection 7.3.8.. Plastic material of high flexibility is attached around the aluminium piece with waterproof tape so that only the shaft sticks out at the bottom. Water is poured into the created plastic basin. The shaft is rotated manually.

Results for shaft opening: Some water is dripping from the mock-up, but it is expected to come from the plastic that surrounds the shaft opening. The test set-up is considered inadequate to examine how well the shaft opening seals. Because of the tight fitting of the O-ring inside the aluminium piece to the shaft, it is expected to seal the prototype sufficiently during submersion for short times.

Test set-up for entire prototype: The shaft openings are glued into the pipe and back cover and thus these connections are sealed. The plane plastic caps at the front and back of the pipe are sealed with duct tape in addition to the O-ring mechanism after it failed in the anterior test. The break-through of the cable that connects the control unit with the remote control is sealed with glue. The entire prototype is submerged underwater horizontally. The shaft connected to the DC motor rotates continuously, the steering fins move occasionally.

Results for entire prototype: After operation of about 30 s the prototype is removed from the water. Through the acrylic front cover it can be observed that there is water in the bottom of the pipe, about 1 cm high. Because all electronic components inside the hull are located safe off the ground another test can be performed. After the second submersion the amount of water has increased. From the ascension of small air bubbles around the pipe it is expected that water enters through the shaft openings. Especially the opening in the back is suspected to leak, where the shaft with the smallest diameter, most rotations and highest side forces (generated by the tail segments) is located.

Conclusion for entire prototype: The applied waterproofing mechanisms are sufficient to conduct first functionality tests with the prototype. For longer submersion better solutions should be developed. In addition, the process drying the robot's inside requires to detach an entire front or back cap and thus takes much time. A small hole on the bottom of the pipe, temporarily sealable through covering it with duct tape, could simplify this process significantly. This way, several tests underwater could be performed in a quick sequence. Nevertheless, it has to be paid high attention to not rotate the robot around its longitudinal axis in case there is water inside the pipe, because the delicate electrical components located in the top could be easily damaged.

7.5.4 Test of the Hull's Immersion

Test set-up: The entire prototype is assembled. According to the buoyancy calculation (7.3.7) weights are added into the pipe: a metal bar of approximately 3 kg and another of 1 kg. The weight's location is at the pipe's bottom and as far in the front as the other components inside the hull allow. The hull is sealed (7.5.3), the spherical head is attached with duct tape and the prototype is put into the water.

Results: The prototype floats on the surface and is stable around the longitudinal axis (it does not rotate upside down), but the tail sinks deep into the water while the front is floating to the surface – even more than to be seen in Figure 33.

Figure 33: First immersion test of prototype

To balance the prototype around its transverse axis the spherical head is detached and swim supports of Styrofoam are attached sideways at the pipe's back (Figure 34). After this adjustment the robot almost floats horizontally in the water.

Figure 34: Prototype with swimming support

Conclusion: This mock-up is not ideal for further functionality tests because the Styrofoam pieces generate high drag and also the prototype floats high on the surface so that the pectoral fins are just submerged. A possible solution is to locate some weight in the spherical front cap instead of the pipe to balance the robot.

7.5.5 Test of Tail's Propulsion

Test set-up #1: The prototype is entirely assembled and sealed. The tail mechanism is composed as considered appropriate in the end of the preliminary motion tests outside the water (7.5.1) with a short bended shaft and elastic bands (Figure 31). The prototype is put into the water and the shaft rotated by turning the potentiometer on the remote control.

Results of test #1: The first three tail segments that are directly actuated by the shaft move as expected. The motion of the last three segments is damped by the water and they almost trail behind without any oscillation. Also, adding more elastic bands and increasing the shaft's bending and length do not improve the motion. Nevertheless, the tail is able to propel the robot forward slowly. The pipe (without any static fins attached) oscillates only slightly around the vertical axis and moves with a straight heading direction.

Test set-up #2: The second last tail segment is removed. The shaft directly activates all segments; there are no elastic bands. The tail segments are attached to the loose back cover and the shaft is rotated manually, first in dry condition and afterwards submerged underwater.

Results of test #2: The tail performs the desired motion when activated in the air (Figure 35 a), as already observed in Subsection 7.5.1. As soon as the tail is submerged underwater, the shaft is not able to make the segments oscillate steadily anymore. The segments tilt and block each other (Figure 35 b).

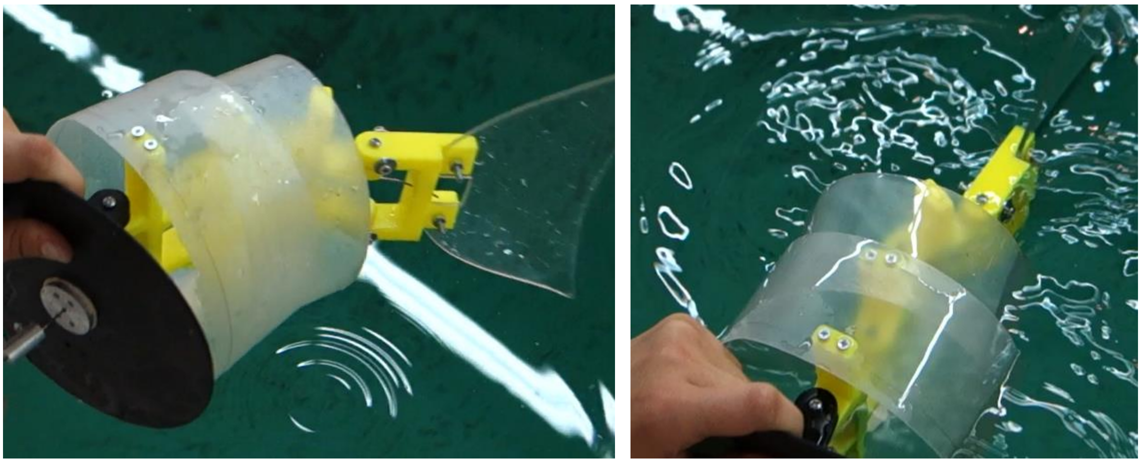


Figure 35: (a) Tail activated in air and (b) underwater

Conclusions: The shaft made from steel spring is assumed to be too weak to transmit forces strong enough to overcome the water's damping forces. A shaft of a bigger diameter might be able to transfer forces sufficiently. Presumably, a DC motor with higher torque is required to rotate this shaft at a steady angular velocity. In addition, a smaller diameter of the segment's holes, through which the shaft is led, could prevent the segments from overly tilting and blocking each other. To maintain the idea of using elastic bands for creating a smoother motion of the tail’s end, the amount of transmitted forces should be increased. This can be done by bending the end of the shaft more, using stiffer elastic bands and/or increasing the distance between the attacking point of the bands and the segment’s rotational axis to generate higher torque.

7.6 Conclusion

In the context of starting to develop an educational toy for children, the target of this chapter was to design a biologically inspired swimming robot that has an easily controllable heading direction in the horizontal and vertical level as well as customizable features, which can teach children about the physics of floating objects.

Based on the considered biological principles and assessment of existing fish-like robots, a BCF propulsion-mechanism was adopted for the robot. The robot has along, articulated tail with a fin at its end to generate forward propulsion,a pair of pectoral fins located at the sides of the body to control the swimming depth and one at the bottom to steer left/right. The main achievement of this development is an innovative approach to actuate and change the undulating motion patterns of the robot´s segmented tail, which resembles the undulating motion along fishes´ bodies.

After selecting suitable components a prototype was implemented. During the experimental evaluation of the prototype´s functionalities, some flaws of the waterproofing mechanisms became apparent. Nevertheless, first tests in the pool revealed the potential of the new tail mechanism to effectively propel the robot forward. A list of possible adaptations was proposed to improve the tail functionalities in the future. The main modification will be to increase the dimensions of component to improve the transfer of forces. Also, the prototype’s longitudinal mass distribution needs to be improved and the tests of steering and submersing performed, which was not possible in the time available for performing tests.

As soon as also these tests have been performed successfully, the prototype can be considered a fully functional swimming robot with submerging capabilities and an innovative propulsion system.

8. CONCLUSIONS

The main purpose of this report was to start developing a construction kit for a swimming robot with biomimetic features in order to arouse children´s curiosity and enthusiasm for technology. The research focused on enabling children to experiment on the physics of floating objects and drawing attention to sustainability problems of the oceans. During the entire development, the team had to bear in mind the marketability of the final product, sustainability issues as well as ethical and deontological concerns.

At first, this chapter presents and discusses the main achievements obtained during this project. Finally, an outlook on future developments is going to be provided.

8.1 Discussion

In the beginning of this project, detailed knowledge about the research field has been gathered. Analyzing several natural and manmade mechanisms and products served as groundwork for the product development and confirmed the innovative character of the toy in the market.

Before starting to develop the actual product, several preparations were performed. The team successfully elaborated and applied project management tools to create a positive, effective and efficient working atmosphere that helped to finish deliverables in time. The marketing plan helped to define the final product in detail. It was revealed that the construction kit for children of eight to twelve years has a unique combination of educational values. A market survey was conducted and plans for a successful product´s promotion and selling developed. In addition to that, research on eco-efficiency measures for sustainability revealed the importance of addressing these topics in order to create a profitable company. As a final preparation, ethical concerns regarding this project were addressed.

Based on this groundwork, a prototype was developed in theory that resembles a fish successfully, ensures steering with a command-response pattern that is easy to handle and makes experimenting on the physics of floating objects possible. A user's manual has been prepared to guide children through experimenting on their final toy. The key concept is an innovative tail mechanism that required functional tests due to its novelty character. Therefore, a prototype has been implemented that is able to float on the water surface. Due to the short amount of time available for the experimental evaluation, not all functionality tests could be performed. Nevertheless, the tail mechanism already revealed its potential to propel the robot forward. It is expected that its efficiency can be increased significantly by applying a list of proposed adaptations to the mechanism.

If the future experimental tests confirm the expected high feasibility and efficiency of the robot with its new propulsion mechanism, this project has not only performed first step towards developing an innovative educational toy for children, but also made an important contribution to the scientific research field of biologically inspired swimming robots.

8.2 Future Development

Following this project, the proposed modifications to the tail mechanism can be performed. They mainly consist of increasing the dimensions of the spring steel shaft and torque of the DC motor that activate the tail segments. When also the longitudinal balance of the prototype is improved, the remaining functionality tests for steering left/right and submersion can be performed. At this state, the prototype will fulfil the initially proposed requirements.

In addition, different fin models (varying in shape and size) can be experimentally tested in order to detect their effectiveness of steering and stabilizing the robot´s locomotion. Also, it is important to develop easier and safer waterproofing mechanisms because children are expected to easily loose their enthusiasm if water leaks inside the robot and components break.

Finally, the other proposed features of the toy, which are to teach mechanics and programming, can be further elaborated by providing a user´s manual for the assembly and templates for programming. Before the final toy is ready for sale, the amount of toxic materials and harmful pieces has to be minimized, holding paramount the enhancement of safety for the user.

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APPENDIX

Number 1: The following survey was done in the "EscolaSecundária do Agrupamento de Escolas de ÁguasSantas" in Porto, Portugal. The results were displayed in the marketing plan in Chapter 4.

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Identificação do respondente:
Seleciona a opção com uma ◯: A. Rapaz B. Rapariga
Idade: ____________________

Nas questões em baixo seleciona a opção com que te identificas!

1. O que preferes fazer nos tempos livres?			
A. Jogar jogos no telemóvel ou *tablets*	B. Estar com amigos	C. Ler	D. Fazer desporto
2. Das disciplinas seguintes, qual é a tua favorita?			
A. Matemática; Física/Química	B. Biologia	C. Português/ Inglês	D. Nenhuma
3. O que é para ti o melhor da escola?			
A. Aprender coisas novas	B. Estar com amigos	C. Os intervalos	D. Nada
4. Das profissões que se seguem, que grupo preferes (A, B, C ou D)?			
A. Arquiteto/a; Engenheiro/a	B. Médico/a; Biólogo/a	C. Professor/a	D. Artista
5. Dos tipos de brinquedos/jogos que se seguem, que grupo preferes (A, B, C ou D)?			
A. *Tablets*/ Computadores; Jogos de computador/ vídeo	B. *Kits* de construção; *Kits* de robótica (robot)	C. Livros	D. *Kit* de pintura
6. Como preferes brincar?			
A. Sózinho/a	B. Com um/a amigo/a	C. Com 2 amigos/as	D. Em grupos grandes
7. Das opções que se seguem seleciona aquela/s com que já brincaste.			
A. Lego	B. K'Nex	C. Meccano	D. Puzzles
8. Dos tipos de atividades que se seguem, qual é, para ti, o mais interessante?			
A. Física (correr; jogos desportivos…)	B. Social (jogar cartas, jogos de tabuleiro…)	C. Criativa (Construction blocks, drawing games…)	D. Destreza (*Puzzles*, *kits* de construção…)
9. Dos animais em baixo, qual preferes?			
A. 	B. 	C. 	D. 
10. Que tipo de peixe preferes?			
A. 	B. 	C. 	D. 

Number 2: User's manual for children to experiment on the physics of floating objects in the water with their "Bro-Fish".

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EXPLORING YOUR "BRO-FISH"

Congratulations! You have successfully assembled your "Bro-Fish". Let's now start exploring how your robot swims in the water!

Attention! Before putting your "Bro-Fish" into the pool, make sure that all detachable connections are tightened properly. When submerging the robot underwater for the first time, observe the water carefully. If you can see any air bubbles arising, remove your "Bro-Fish" immediately from the water because there is a leaking spot! After drying the robot's insides, try to repair the cause of leakage. If you have any problems and questions, feel welcome to contact us via *swimmingrobot@gmail.com*.

Discover your Bro-Fish! Finally, let's discover the features of your toy! After you have assembled and programmed your "Bro-Fish" successfully, you are already familiar with the functionalities of its remote control. Just put the robot in the water now and see what happens if you activate different parts of the robot. You can follow these instructions to explore more features of your "Bro-Fish". Never forget to carefully observe the reactions of your robot after every modification!

1. Change the rotation speed of the DC motor that activates the tail.
2. Change the shape of the shaft that is led through the tail.
3. Change the rotation angle of the bottom fin.
4. Change the rotation angle of the pectoral fins.
5. Replace the tail, bottom, static and pectoral fins by fins with other properties. Therefore, cut out any desired shape and size from plastic or buy our add-on package and attach it to your "Bro-Fish". Try also different materials of other flexibilities. Only replace one fin at a time to better see its influence on the robot's swimming behaviour.
6. Change the amount and distribution of masses in your "Bro-Fish". Move the weights more to the front/back or left/right.

Understand it! Now try to create your "Bro-Fish" with the features you desire, for example, make it achieve high speeds or great maneuverability. You can practise your skills on an obstacle parkour and finally, enter one of our competitions to compete against other "Bro-Fish".

