Thymio: a holistic approach to designing accessible educational robots

THÈSE N^{O} 6557 (2015)

PRÉSENTÉE LE 17 AVRIL 2015

À LA FACULTÉ DES SCIENCES ET TECHNIQUES DE L'INGÉNIEUR
LABORATOIRE DE SYSTÈMES ROBOTIQUES
PROGRAMME DOCTORAL EN SYSTÈMES DE PRODUCTION ET ROBOTIQUE

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

POUR L'OBTENTION DU GRADE DE DOCTEUR ÈS SCIENCES

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ÉCOLE POLYTECHNIQUE
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Suisse
2015

A mon papa François et mon oncle Jean-Pierre

Abstract

Technology is now an important part of our lives. We often see robots cited as the future of education, and reports of their imminent entrance in schools. New projects create buzz in the media and online, but when we look at the actual situation, very few robots are currently used in education, and most of the time, the platform used is the Lego Mindstorms. Why so little diversity? What do robot actually bring to the learning experience? How can we design good educational robots?

Hopes are that they bring additional motivation to pupils. Since the use of robots is fun, the learning is supposed to become easier. Robot projects and activities are also expected to foster thinking skills, collaboration, and creative spirit. Finally, there is a need to educate people on technology for two reasons. The first is to break the “black box” image they have of technology, and the second is to encourage them into technical careers.

Thanks to the Swiss National Centre of Competence in Research Robotics (NCCR Robotics), we could develop some innovative concepts in educational robotics, and implement one such pedagogical tool. We designed a small wheeled robot with many sensors, and LEDs making its internal state apparent to the user. A simple, white look makes it a neutral base for creating one’s own application, for all age and gender groups. Different user interfaces allow to make it accessible to everybody:

- Pre-programmed behaviours that demonstrate its different possibilities
- A Visual Programming Language (VPL), without text and based on event-action pairs
- The Aseba script language (text-based), with a comprehensive development environment to accompany and inform the user

The resulting platform, *Thymio II*, is completely open-source and open-hardware. It was mass-produced and commercialised at a low cost. This gave the opportunity to evaluate the public’s response to it.

We could assess that the robot design is well received and appreciated by different age and gender groups. It seems particularly popular with girls. We analysed the expectations of the different age categories and proposed activities that fitted their specific needs.

We could also validate that users of Thymio II learn notions of programming, understand essential concepts such as what sensors are, what is the relationship between the robot, the computer, and the programming environment. With the VPL, they could quickly grasp the meaning of events and event-action pairs.

We realised that in spite of the interest it generated, the robot was not used much at home or in schools. We think that there is a need for more guidance and that parallels should be drawn with e-learning for the use at home. In schools, we observed that teachers who use robots are pioneers, who invest time and sometimes money into new technologies out of personal interest. The others do not feel strongly against robotics but are probably discouraged by the lack of institutional injunction, appropriate training, budget, and ready-to-use pedagogical materials.

At the end of this work, we conclude by giving a set of guidelines, based on our experience, for the design of educational robots. This project demonstrated very promising results and we believe that it can be a first step toward renewing teaching habits.

Keywords: educational robotics, robot acceptability, programming for children, teacher attitudes towards technology, affordable robotics, mobile robotics

Résumé

La technologie fait désormais partie intégrante de nos vies. Les robots sont souvent présentés comme le futur de l'éducation, et des promesses sont faites de leur apparition imminente dans les écoles. De nouveaux projets font grand bruit dans la presse et sur la toile, mais lorsqu'on examine la situation actuelle, très peu de robots sont effectivement utilisés dans les écoles, et en majorité ce sont des Lego Mindstorms. Pourquoi si peu de diversité ? Qu'apportent réellement les robots à l'apprentissage ? Comment concevoir des robots efficaces pour l'éducation ?

Les attentes sont généralement les suivantes : les robots apporteraient un surcroît de motivation aux élèves, et du fait qu'ils sont divertissants, l'apprentissage devrait se faire plus aisé. Les projets et activités utilisant des robots sont de plus supposés améliorer et encourager la capacité de raisonnement, la collaboration et l'esprit créatif. Enfin, il y a une demande pour plus d'éducation de la population à la technologie pour deux raisons. La première est la volonté de briser l'image de "boîte noire" que les gens en ont, et la deuxième est le désir d'encourager les jeunes dans les carrières techniques.

Grâce au Pôle de recherche National en Robotique (NCCR Robotics), nous avons pu développer de nouveaux concepts en robotique éducative et les implémenter dans une plateforme robotique. Nous avons conçu un petit robot à roues, doté de nombreux capteurs et diodes lumineuses qui rendent apparent son fonctionnement interne. Son apparence simple et blanche en fait une base neutre pour que chacun puisse faire sa propre création, adapté a tous les groupe d'âge et aux filles comme aux garçons. Les différentes interfaces utilisateur le rendent accessible à tous :

- Des comportements pré-programmés qui illustrent ses différentes possibilités
- Un langage de programmation graphique (VPL), sans texte et basé sur des paires d'action-événement
- Le langage texte d'Aseba, avec un environnement de développement complet pour accompagner et informer l'utilisateur

La plateforme ainsi créée, *Thymio II*, est totalement libre, tant pour ses sources logicielles que sur les aspects matériels. Il a été produit en série et commercialisé à bas prix. Ceci nous a permis de récolter et évaluer les opinions d'un grand nombre d' utilisateurs.

Nous avons pu vérifier que le robot est bien perçu et apprécié par les différents groupes d'âge et de sexe. Il semble particulièrement populaire auprès des filles. Nous avons pu analyser

les attentes de ces différents groupes, et avons proposé des activités correspondant à leur demandes spécifiques.
Nous avons également pu vérifier que les utilisateurs de Thymio II acquéraient effectivement des notions de programmation, comprenaient des concepts essentiels comme ce que sont les capteurs, et quel est le lien entre le robot, l'ordinateur et l'environnement de programmation. Avec VPL, les utilisateurs ont pu rapidement saisir le sens des événements et des paires d'action-événement.
Nous avons réalisé que malgré l'intérêt généré, le robot n'était pas très utilisé à la maison ni dans les écoles. Nous pensons qu'il y a un besoin pour plus d'encadrement, et que des parallèles peuvent être tirés avec les technologies d'e-learning pour l'utilisation domestique. Dans les écoles, nous avons observé que les enseignants qui utilisent des robots sont des pionniers, qui investissent leur temps, et parfois leur argent, dans ces nouvelles technologies, par intérêt personnel. Les autres ne s'opposent pas à la robotique, mais sont probablement rebutés par le manque d'injonction institutionnelle, de formations adéquates, de budget et de séquences pédagogiques prêtes à l'emploi.
A la fin de ce travail, nous concluons en donnant une liste de recommandations, basées sur notre expérience, pour la conception des robots éducatifs. Ce projet a montré des résultats très prometteurs, et nous pensons qu'il peut servir de premier pas vers un renouveau de certaines habitudes dans l'enseignement.

Mots-clés : robotique éducative, acceptabilité des robots, programmation pour enfants, attitudes des enseignants envers la technologie, robotique abordable, robotique mobile

Acknowledgements

Doing a PhD is certainly not an easy task, and without doubt not one I would have accomplished without the support of many others. I would like to thank all the people who helped me, taught me, entertained me during these four years.

First of all, of course my supervisor, Prof. Francesco Mondada, without whom there would have been no thesis at all. Thank you for welcoming me to your team, and for your openness of mind. I am especially grateful that you gave me the opportunity to develop a robot that reached so many people. Thymio II would not have existed without your effort to create real collaborations.

I'm very grateful also to my co-supervisor Prof. Pierre Dillenbourg and his team for their inputs and different points of view on our venture with Thymio II. I deeply appreciate that you used our group's robots, prototypes or finalised products, in your experiments.
I thank also all my thesis committee members for their interest and careful reading: Dr. Pericle Salvini, Dr. Gilles Caprari, Prof. Auke Ijspeert, Prof. Jamie Paik.

All my gratitude to the Thymio development team: Michaël, Philippe, Luc, Laurent. We created a great robot. A special mention to Philippe who taught me so many things and listened patiently to my stupidest conversations.
A big thanks to the Aseba team and especially Stéphane for their great work.

So many other people contributed to the success of Thymio II, it's hard not to forget any. Morgane Chevalier, Gordana Gerber, Nathalie Nyffeler, Andrea Suriano, Jean-Maurice Mayencourt, Antoine Régamey, Laurent Michel, Grégoire Aellig, Monica Prieto, Olivier Renault, Pauline Ruffiot, Marion Albertini, Nathalie Bonani, Manon Briod, Maria María Beltran, Moti Ben-Ari, and many others with whom I have not had direct interactions: thank you all for your inputs, and your trust in our project.

Huge thanks to Frédéric: thank you for all your careful proofreading, for your positive messages and support. You are truly a unique friend.

A big thanks to all Mobots group members, present or former, who make robots come to life thanks to the great collaboration they share, and especially Christophe, Mariza, Philippe, Michaël, Florian, Dany, Norbert, Alain, Anne. I will always keep fond memories of the good times we shared: sushi-Thymios, Christmas movies, chinese movie, Mobots lunches, horoscope-reading sessions, coffees at satellite, etc.

Thank you Julia for your support and for showing a good example :-) You made me believe again that I could make it!

I would also like to thank all my friends for taking my mind off things.
Thanks to Guillaume for the ponies and for all the interesting discussions.
Thanks to Sophie and Léonore for being my best friends.
Thanks to all bollywood girls for entertaining me and for you support: Céline, Alexandra, Séverine, Alexandra.
Thanks to all my friends from Collège Sainte-Croix, for remaining my friends through the years.

Things would not have been so nice without the support of my family: Olivier, Nicolas, Karin, Bastien (who stole my thunder by learning how to walk the same week I passed my private defense) and my parents, Catherine and François. I owe it to you that I am interested in everything, that I became strong, and made it so far.
I also thank my new family for welcoming me with open arms and encouraging me, Valentina, Vladimir, and Sergey.

Finally, my deepest gratitude to Alexey, my dearest friend and my favorite post-doc. Thank you for understanding me so well. Your support means more than I can express.

Lausanne, 25 Février 2015 F. Riedo

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1 Introduction

Robots are strong figures in our collective psyche. In science fiction movies, they are artificial beings that outperform us humans in all domains, sometimes negative figures that could take over the world. Since several decades people expect the moment where service robotics will be omnipresent and perform the menial tasks for us. They fascinate and scare people at the same time, yet in reality even vacuum cleaning robots are hardly present in our homes and do not provide entirely satisfying results. While the omniscient robotic teacher is still far away, robots are often mentioned as a promising tool for education.

The National Centre of Competence and Research Robotics (NCCR Robotics) provided an opportunity to investigate this topic. In this chapter, we will explain where the high expectations in robots for education come from, and discuss the robot's role in the context of a school. We will debate the benefits they could hold. Finally, we will motivate our own venture into creating robots for education, and describe our objectives for this work.

1.1 Robots: a tool for education?

Since Papert's work in the 1980's [Pap80], robots have often been touted as the future of education [Res93], [CKHD99], [Joh03], [MNS08a]. Of course they are quite present in universities and technical schools [GCF+01], [HPB05], [MBR+09], [MFG99] where they serve as a learning platform for programming, electronics, artificial intelligence or system integration. But when we look at a younger age range, they are still not the outstanding tool they were expected to be, and actually technology itself has a hard time entering classrooms [CKP01]. Few schools use robots regularly, and when they do, the diversity is limited, and very often they are part of occasional, fun activities. In many of the initiatives reported in the scientific literature [Ben12], the chosen robotic platform is the same (Lego) and topics taught are restricted to STEM (Science, Technology, Engineering and Mathematics).

Did something prevent robot from entering schools? Do they have a place in schools in the first place? Is there a unique selling point in robots that brings real benefits to education? Are all those expectations justified or is it just a trend bound to fade away?

In the next sections, we will discuss the expected benefits of robots in schools to understand the source of this trend. We will also give an overview of the different roles robots could have towards the pupils, the context in which they will be used, and the topics that can or should be taught. Finally we will define the general objectives of this work.

1.2 Perceived benefits

When looking at the literature about the introduction of robots in education, we see different supposed benefits.

1.2.1 Doing is learning: the constructionist approach

At first, starting with Papert and his constructionist point of view, is the idea that "doing is learning" [Pap80]. This approach focuses on the students and their learning, through project-based exercises where the teacher's role is to coach students as they build their own path by using their knowledge and ideas. Papert gives particular importance to the tangible aspect of making something in the real world; this is for him the most effective context for this constructionist approach.

Robots embody these aspects very well [KR96]: a polyvalent robotic platform can serve as a starting point for many different projects, and the students will be able to see it progress in front of them, interact with its environment, and thus they will really make the experience of its behaviour. In addition, by developing their own project, they can appropriate it, enhancing their engagement [Bla06].

1.2.2 Enhanced motivation

When robots are used in classes, higher levels of motivation from the students are also hoped for [Joh03], [RdSA04]. Because of the novelty effect, or because it breaks the routine, robots generally provoke the enthusiasm of the users. They move, produce sounds or light, making the students curious and wanting to interact with them [KHEI04].

However, it is worth noting that most articles pertaining to the usage of robots in classes report isolated workshops or short term projects, thus the novelty effect might be the major factor in this phenomenon.

1.2.3 Fun makes it all easy

Linked to the enhanced motivation is the perception that having fun means learning more easily. Playing would be a way of motivating people; gamification of tasks and serious games are developed in order to let people learn “without realising” it, turning a chore into a pleasant activity. This idea, linked to that of serious games [MC05], comes from the observation that video games are very engaging, and players can put lots of efforts to train and learn things in order to finish the game. Investigating this in order to create serious games that retain this quality could bring great benefits to the engagements of students and pupils [DFJ07].

1.2.4 Projects encourage collaboration, thinking skills, and creativity

The project based approach, that can be easily implemented with robots, might help develop transversal skills [GZ13].

Group projects are expected to enable pupils to communicate better and to develop collaboration strategies. As robots are intrinsically interdisciplinary, succeeding in a project would require pupils to develop strategies, to plan their work and to coordinate the different aspects of a project. When testing their creation, they need to use strategies such as scientific analysis or trial-and-error process, emit hypotheses, verify them.

Hopes are that using all those skills in context will help the pupils to master them, enabling them to transfer those skills to other problems.

1.2.5 Robots will make you love technology

Finally, there are external motivations to introduce robots in schools. Those focus on the robot as a good way to introduce technology-related lessons in school. Two main reasons lead to the will to teach more about technology.

The first comes from the observation that technology is becoming omnipresent in our daily lives. However, most of it is seen as a “black box”, or a magic device. Users have no clue of what is happening inside; their idea of technology becomes disconnected with reality. Studying robots and what happens inside could help break this “black box” image [Nag01]. Because of this ignorance, some people develop fear of the technology. A striking example was brought to our attention by one of our teacher collaborators. She told us the case of a primary school teacher, who opened all windows in the room during an activity with iPads, to “let the waves out”. Another survey shows that people are afraid of robots taking their workplaces [RMS08]. The special Eurobarometer on public attitude towards robots [Eur12] confirms this fear towards robots: 60% of the interrogated people think that robots should be banned from the care of children, elderly and disabled people. In addition, 34% consider that they should be banned in education, and 27% in healthcare. They seem not to trust this technology, which is ironic when on the other side, scientists promote healthcare, care of the elderly and education as fields where robots could bring strong benefits [HTK+05], [RBF+00]. Bringing technology into schools could help make people more knowledgeable about it, enabling them to judge for themselves what is useful, dangerous, or reliable, because understanding robots might give wider skills to understand systems in general [Sul08].

The second reason comes from the fact that fewer and fewer people get interested in technical studies, while the need for engineers is increasing. We expect that by having technology-related activities at school age, pupils would become more aware of this possibility and consider it as a career choice [WHS10]. It could especially reach out to groups who are not usually aware of this possibility, like girls [BL10], or children labeled as "more creative" [RRBPG08], or those who dismiss all technical subject because they experience, for example, difficulties with mathematics. Indeed, mathematics are crucial in the career choice, and students will not go for technical or scientific studies if they do not feel confident with maths [dTW14]. Girls especially, seem to suffer from a sociological bias; ethnic minorities are also not equally represented in technical fields [CLB+07].

All those expectations led to several endeavours to develop robots with educational purposes. In the next sections we will go into more details of how exactly it is implemented, what role the robot takes, what children are expected to learn with it.

1.3 Place of the robot in the learning process

How exactly can the robot help a child to learn? Robots themselves can take different shapes and sizes, and interact in different manners with the user. We will go into more details of the role they can take, and the environment in which they will be used.

1.3.1 Role towards the pupil

When talking about robots for education, people imagine all sorts of possibilities, from a small wheeled robotic kit as the subject of study, to the life-size humanoid teacher that talks to children. We can distinguish between different roles for the robot to take towards the children. [MSS+13] separates the roles into three categories: tutor, peer, or tool. However, it seems relevant to us to distinguish a fourth role, that of object of study, which is maybe not the most desirable, but still often encountered.

Object of study

First, we'll define what it means to have the robot as an object of study. The pupils' learning will revolve around it, they will learn about it by observing or interacting with it, or by making exercises or enquiries. In this case the topic taught is logically robotics, or closely related fields, like electronics or programming. The limitation of this role is that the lesson only aims at studying a particular instance of a robot, without expectations of transfer, or of learning another topic.

Tool

The second role, slightly different, is that of medium, or tool, to learn about another topic. Just like pupils could have learnt using books, written exercises, computer applications and so on, they can do exercises with the robot. The robot however is still seen as a machine, or an object, and the social interaction is not essential. In this case, a transfer is expected: the knowledge acquired should be more general than a simple case study. It should be usable even without after the lesson in another context, be it second language vocabulary or essential notions of programming like conditions and loops.

Peer

Thirdly, the robot can act as a peer or a companion to the child. In this case, it will accompany the child in his studies by learning at the same time. The interaction between the child and robot, correcting each other, takes a primordial role. The social aspects and the capacity of the robot to communicate with the child is essential. A more emotional engagement is expected from the child, and often there are hopes that the child will feel motivated by the interaction, but at the same time comfortable and not afraid to make mistakes.

Tutor

Finally, the robot can teach itself; it takes the role of the tutor. Once again the social link is essential. In this case, the robot holds the knowledge and the correct answers; in addition to encouraging the children and supervising their work, it serve as a reference, a reliable source of information. It assumes a superior position with respect to the child.

1.3.2 Environment

The context in which the activity with the robot happens can also change, influencing the robots' features and characteristics, as well as the activities themselves. The learning can take place at school within the curriculum, in extra curricular organised activities, or at home in autonomous work.

At school

When at school, several constraints weigh on the activity. The official program should be respected, and robotics or technology related topics are not generally part of it nowadays. That means robots will integrates classes only if they are used in activities related to standard curricula topics, or by a teacher's personal initiative. In this case the teacher's interests and motivation take a fundamental role in the introduction of robots in class.

In addition, the format of the sessions needs more structure and goals, teachers need to plan their lessons knowing how long an activity will require. They need efficiency, because they need to move on with the whole program. Sometimes a more open-ended, creative, discover-by-yourself activity can take more time than a conventional way of teaching to cover the same material.

Finally, it requires the teachers themselves to be proficient with the robotic platform.

In extra-curricular group activities

Extra-curricular activities share some characteristics with school lessons, but enjoy much more freedom in their execution. They can take the form of a lesson directed by a coach, or of a more open-ended activity like a personal project development. Because they are not linked to any directives concerning the educational objectives, the topics taught can be much more varied.

Extra curricular activities typically happen in schools outside of normal class hours, in clubs, during special events such as festivals or outreach campaigns or in specific centres like those of the Roberta initiative [Fra09].

A key characteristic of those activities is that contrary to school, they are purely optional, thus we can safely assume that attendants will show interest and start with a positive bias. Therefore, this kind of environment does not fit best the objective or reaching previously uninterested children and arousing their curiosity.

At home

At home, a robot can be a great support also for a child to learn alone. This is often seen among hobbyists with robotic kits; in this case, very often a person interested in robotics, electronics, programming or wanting to build a prototype of some sorts will find a kit or platform and will learn by themselves. Internet has an important place in this context, as a source of information or help. Communities grow quickly around a platform with examples and users advise each other, for example with Arduino [CJN12].

In the same way, a child could work autonomously with a robotic platform at home. Similar to this, we can find examples of holiday exercise books or specific software for children to train by themselves. Some of them take the form of games, aiming for a stronger motivation. In this case, a carefully designed robotic platform could prove an interesting tool, possibly adapting to the child's level, motivating them, or even providing coaching.

In this work however, we will concentrate mostly on group activities, especially on those that can be implemented within schools and their curriculum. Extra curricular activities however will be investigated, because they are often a first step, or a less constrained implementation, before teaching material is ready for schools.

1.4 Topics taught

We have mentioned them briefly in the previous sections, but we will now look more closely to the different topics that could be taught with the help of robotics. We will see that different topics bring different constraints and influence greatly the platforms themselves.

1.4.1 Robotics

The first subject that comes to mind is of course robotics themselves. This is when the "learning by doing" approach takes all its sense; if someone plans and then creates their own robot they will likely understand its functioning deeply, because they have implemented it, and probably faced problems and solved them. We could say that because succeeding with the project can only happen if the topic is understood, contrary to an approach where the pupils only listen, read, or repeat, where they feel they understand, but then cannot apply or use this knowledge autonomously.

We can also expect that by developing their own idea they will have stronger motivation and a great sense of achievement once the project works. But "robotic" as a topic is not a very well defined: it can encompass notions of mechanics, electronics, programming, construction, etc. The knowledge gained during a certain project might be restricted to the particular obstacles encountered, and harder to transfer to other situations.

If not developing a whole project, robotics can also be approached through its different aspects, in a more targeted manner. This is seen in "introduction to robotics" sessions, and often concentrates on construction aspects or on programming a behaviour, lower level aspects being left aside, especially with children [JKK08]. The type of robots seen in this case can be kits like Lego Mindstorms, programmable wheeled robots or boards like Arduino.

1.4.2 Technical fields

If not teaching robotics, the topics essential to building robots come to mind. A robotic platform could help learn about the topics that are essential to its conception like electronics, mechanical design, artificial intelligence and so on. The difference with the previous case is that now the question is not anymore "What are robots?" or "How do robots work?". The robot takes the role of one example, one implementation of the discipline studied, for example in computer science [Bla06]. Students or pupils are expected to transfer this knowledge to a broader field and they know it. As explained by [Pap80], announcing explicitly the transfer makes all the difference in the student's ability to actually use the acquired knowledge in another context.

The other difference comes from the fact that as the topic is defined, other disciplines are seen as obstacles and should be gotten rid of so to speak, to let the student concentrate on what they should learn. Therefore, the platform needs to correspond to the topic taught. For example, a university course about artificial intelligence might use complete, functional robots, seen as "black boxes", with a test environment. The students then focus on the high level programming, all libraries being already available. A course of embedded programming on the contrary, while it might feature ready to use robots also, might concentrate on lower level programming, looking into data sheets of the components or into the schematics. For example in the courses our laboratory gives to bachelor students, the e-puck [MBR+09] is the main platform. The fact that it is open source and open-hardware allows students to look into details needed to program low-level functions.

With a younger public, the topics might not yet be so specialised, but we can give an example of electronics practicals that use Arduino boards [Gen14]. They are accessible, yet allow for construction of small circuits.

1.4.3 Non technical fields

We can then move further away from the field of robotics to the teaching of other topics, such as science or even languages. Indeed robotics has links to many different disciplines [SCM+12]. Most applications we know of are in science, for example in geometry, as was proposed by [Abe86] (first in simulation and then with *floor turtles* [McN04]), or in mathematics [HMH08]. We also find examples with second-language courses [KHEI04]. In this case, the robot takes the role of a tool or a medium used by the pupil. It could also take the role of a companion, or that of a teacher.

The point in using the robot here is generally to enhance motivation and attract attention, or to disrupt the routine of the class, by using the robot's interactivity. The pupils can then test their knowledge by themselves and see the result. We can also note that this is seen mostly in education of children. We have not heard of cases of robots used to study science or languages at a university level.

Once again, the platform chosen will depend greatly on the context, and the pedagogical material surrounding the robot becomes most important. For example, in primary schools, games using Bee-Bots allow to train mathematical operations [HMH08] or learn how to read [Aub11]. All the difference resides in the mat used and the rules of the game.

1.4.4 Transversal skills

Finally, we mentioned previously transversal skills, such as communication, collaboration, developing strategies, or analytical and creative thinking processes [MNS08b], [MNR09]. Especially in problem-based learning approaches, these skills are expected to emerge and be assimilated by the students [DH01]. The teacher or coach will encourage the usage of such skills by asking questions or suggesting things when the students encounter problems. The discussion of a project's status allows to take a step back and to analyse those problems.

We notice that here again, like with the previous topics, the fact that the platform used is a robot is accessory; it could be done also with another project. The choice of a robot could then be motivated by the hope it will catch the student's interest, or because the pedagogical objectives are joined with another one more closely related to robotics. In addition, robotics platforms seem to foster especially creativity, because of the construction and customisation possibilities they offer.

Before moving on to defining the scope of this work and our objectives, we will quickly note that robots are also used in specialised education for example with autistic children [DW04], [FRD09]. However, in this work we will not cover those topics.

1.5 Motivation and objectives of this work

We started this chapter with an overview of how and when robots are expected to be used in education. They are not yet a standard tool, but people imagine all sorts of applications, and examples go in all directions. We started from the observation that despite all the arguments found in literature, robots are not often found in Swiss classrooms. They are not part of the official curricula, and very few teachers told us that they actually used robots in class on a regular basis. We will try to understand why the robot's presence in schools is so limited.

Because of the very nature of this question, we will concentrate on initiatives involving children, from primary to high school. Those are also the target group where all the perceived benefits described in Section 1.2 make sense. Indeed, in order to raise interest for technical careers, children should be reached at an early stage, before orientations start to split. Also, to raise awareness and promote the understanding of the omnipresent technology, the easiest way to reach all categories of population is through compulsory schools. In addition, much of the debate on whether to integrate robots in schools for which purpose concern these levels too.

We will first look at the existing robots and the reported experiences to determine what worked and what did not work We will analyse which are the most common platforms and what is generally taught, and with which success. Those experiences will be used as lessons learnt in the next steps of the work.

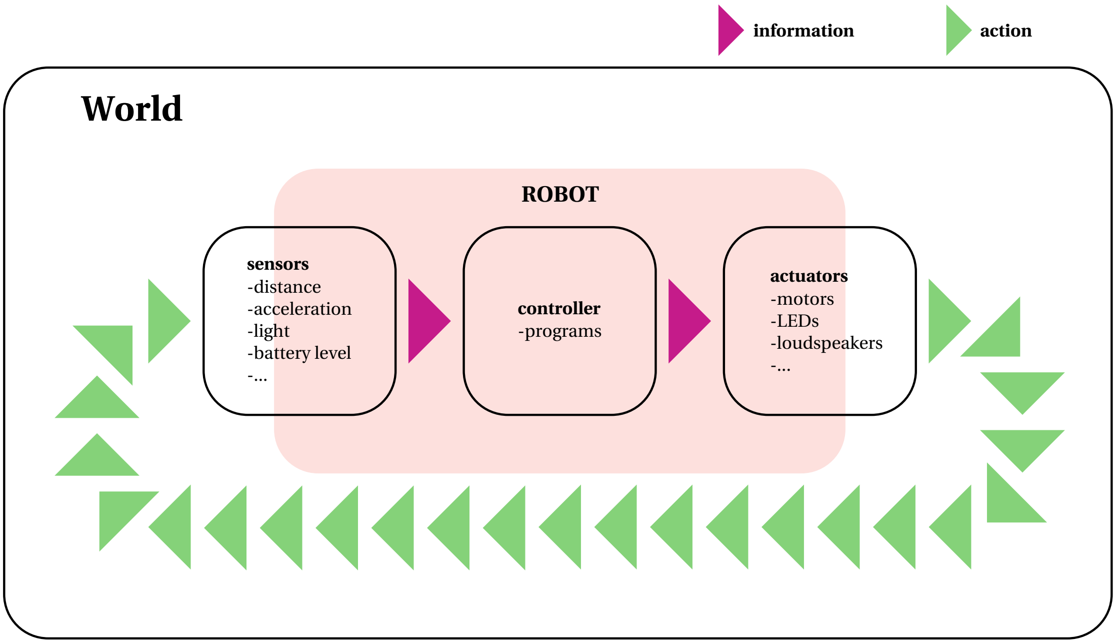


Figure 1.1 – The sensor-actuator loop (original image by Stéphane Magnenat).

On the topics taught, we will restrict ourselves initially to introduction to technology and fields closely related to robotics, as well as to observe the impact on the transversal skills. The reason for this decision is that we consider it a good first step in understanding the dynamics happening between the robot, the pupils, and the teachers. By concentrating on a field we know, we can already study many aspects of the integrations of robots in the school curriculum without cumulating the risk of finding new methods to teach something already integrated, with the risk of having a badly designed tool or that of misunderstanding the social dynamics of the acceptance of such a new device. Also, we consider that robots are an excellent illustration of the concept of sensor-actuator loop, which is a core element in the understanding of technological devices and for scientific outreach.

This concept, or rather its generalisation as a sensor-actuator loop, is a key to grasp technological systems in general. It consists of three different types of entities (see Fig. 1.1): sensors, that perceive characteristics of the world, actuators, that can act in this world, and a processing unit, that takes decisions depending on what was sensed to do something through the actuators. This system also allows to introduce the notion of feedback, essential for intelligent behaviour. Understanding the sensor-actuator loop can help analyse all the technical devices that surround us. While the effect of actuators is obvious because it directly impacts the world, like a lamp producing light, a motor turning a wheel, or a loudspeaker playing music, sensors can go unnoticed and seem passive. However, they are present everywhere, in cellphones, in shop security systems, in cars, and so on. Robots make it very easy to show these three basic units, and by modifying a robots program or interacting with it, children should be able to internalise this notion and then project it on other devices, breaking their “black box” aspect.

In this thesis we will design, implement, and study a robotic platform for children, based on our previous experience as well as on our analysis of the existing platforms, which fits our vision of promoting the knowledge of technology, even at a very young age. We aim at having a polyvalent tool, that is appreciated by different age categories, and offers adapted environments and activities to different categories of children. We will study the motivations and obstacles to robots' presence in schools, in order to have a global vision of the problem and understand its issues.

In the next section, we will look at the state of the art, analyse the results of enterprises similar to ours, and explain why we decided to develop our own tool. We will go into more details of the characteristics it should have. In addition, we will give an overview of the methods used to determine the efficiency of a robot as a pedagogical tool.

2 State of the Art

The literature is quite abundant when it comes to robots used for educational purposes. In this chapter we will try to give an overview of what currently exists, and how it is used. We will first describe available platforms and classify them into different categories according to their physical characteristics:

- Humanoids
- Kits and boards
- Wheeled robots

This distinction is motivated by the fact that the type of robot is closely related to its use in education. Other types of robots exist, such as animal shaped and flying robots or robotic arms, however we found few examples of them being used in education of children. Similarly, we will not cover simulated robots, which in our opinion are closer to educational softwares on computers and to serious video games, because of the context they are used in. They lack the tangible aspect of robots and their physical presence. Finally, some projects have already gained popularity because of Kickstarter campaigns and such, but have not been released for the public yet, for example JIBO [JIB], Wonder Workshop's Dash & Dot (previously Play-I's Bo & Yana) [Won] and Edison [Mic]. We will not cover them as they do not have user experience yet. The robots we will cover will include commercial and research robots, with the selection criterion that they are intended for or have been used with children.

We will then discuss the existing programming interfaces that let children determine their robot's behaviour. We will explain their specificities and how they can be adapted to suit the needs of the younger ones.

In a third section, we will take a look at the current research results on the efficiency of robots in education. We will also try to understand what the challenges are for the evaluation of educational robots. Finally we will draw conclusions that will help direct our own work.

2.1 Existing robots and kits

Many robots have been used with children, whether they were especially designed for this purpose, or they are adopted by teachers or educators though they were intended for another public. In this section we will list the most relevant examples of robots and give their main characteristics, as well as the context in which they have been used for education.

2.1.1 Humanoids

Humanoids come to the mind of most people when they are asked about robotics. This might be due to the influence of popular culture elements such as science fiction movies. The word “robot” itself originally designated artificial beings, who were fabricated to work and could be confused with humans, in Karel Čapek’s play [Čap04]. The notion of robot evolved with the development of industrial robots, generally motorised arms with tools that replaced people on production lines, and with vehicle-shaped research robots. Humanoid robots exist however, and some of their characteristics are exploited in education.

One of the most publicised humanoids was built by Honda: the *ASIMO* [Hon14] (see Fig. 2.1a). A bit smaller than a human, ASIMO exists only in limited numbers and is not intended as a product for the lay people. While it was designed as a demonstrator and not as a tool for education, [ONTHS09] used it in experiments as a tutor or a peer to interact with four- to ten-years-old pupil learning how to set a table. This pilot study aimed at understanding the child’s interaction with a humanoid robot in different roles, and learning was assessed with a post-test. The benefit for education in this case would be higher motivation on the part of the child and longer attention span, the robot’s presence being an encouragement. While this study gives hints that cooperative learning with a robot leads to better results, this setup is not applicable in real classes. ASIMO is too expensive, potentially dangerous for the child without supervision, and requires a hidden human operator.

More platforms exist, that are more affordable and especially designed for education and amateurs. ZMP’s *e-Nuvo WALK* (see Fig. 2.1b) is a simplified humanoid robot with 12 degrees of freedom designed for the study of control systems [ZMP14]. Reduced to a pair of legs, it is programmed through Microsoft Robotics Developer Studio, or through a graphical programming language, thought not especially designed for children, with a simulation also available.

Gogic Player by Elekit (see Fig. 2.1c) is a much simpler robot with only 5 motors, that features also a few sensors [Ele14]. It costs JPY 34’560 (approximately CHF 287). It has its own software, Gogic Works, which does not allow too complex motion according to [BLMM13]. With extension packs, it can be transformed into a robotic car.

Vstone offers several several humanoid robots [Vst14], the simplest being *Robovie-i* (USD 270[1]) for beginners, intended to be handled even by primary school pupils (see Fig. 2.1d). It has 3 degrees of freedom, and decoration stickers to allow customisation by the children. The next step is the upgrade to *RB2000* (USD 815[2]), a 2-legged robot with 13 degrees of freedom (see Fig. 2.1e). Then come *Robovie-nano* (USD 880[3]), 23 cm high with 15 degrees of freedom and finally *Robovie-X* (USD 1'120[4]), 35 cm high and 17 degrees of freedom (see Fig. 2.1f). There are dedicated softwares to program those, RobovieMaker and its evolution RobovieMaker-2. As it is not easy to control all degrees of freedom by setting targets separately, the software allows to define poses, which are then put into sequences.

As noted by [BLMM13], these platforms are intended for the japanese market, thus most of the pedagogical material is available only in japanese. A field trial has been made in Japanese elementary schools, in English classes [KHEI04]. In this case the robot serves as a motivator with which the pupils can interact. Two robots were left in the class for 2 weeks and pupils could come and talk with them, with more than 200 pupils involved. The idea was that as the robots spoke only English, the pupils could practice and realise the importance of this language, and the first observations confirm this.

The Korean *IROBI* (see Fig. 2.1g) offers several services, among which home tutoring [HJPK05]. Not intended to be programmed by the user, it will rather act as a tutor or partner with applications suited to the topic learnt. In their first study, they used it in English lessons for sixth graders. Compared with other e-learning techniques, the results were encouraging.

In Europe, Aldebaran proposes *Nao* (see Fig. 2.1h), a 58 cm humanoid robot with 25 degrees of freedom and several sensing capabilities [Ald14]. It has specific embedded software, NAOqi, to ease its programming. It has been used with autistic children [TPA+12], [SYI+12] in activities of socialisation. It costs around USD 8'000[5]. Materials to teach control, computer science, mechanics and electronics to middle and high school students also exist [CL12].

Robotis' *DARwIn-OP* [Rob14] has 20 degrees of freedom and good sensing capabilities, measure 46 cm and costs USD 12'000[6] (see Fig. 2.1i). It is intended for research and higher education, and requires advanced programming. This project also follows the open source philosophy [HTA+11]. It has been used in several robotics competitions: IEEE ICRA DARwIn-OP Humanoid Application Challenge, RoboCup and FIRA HuroCop.

WowWee's *Robosapien* [Wow14] is at the lower end of the price range with a price below USD 100 (see Fig. 2.1j). Its functionalities however are limited, mostly only to remote controlled movements and memorisation of a short sequence. But with modifications to extend its

[1]Price from www.engadget.com/2006/05/19/vstone-goes-affordable-with-robovie-i/
[2]Price seen on www.roboteshop.com
[3]Price seen on www.roboteshop.com
[4]Price seen on www.japantrendshop.com
[5]Price seen on shop.robotslab.com
[6]Price seen on shop.robotslab.com

capacities, the robot was successfully used as an affordable platform for the 2004 RoboCup Humanoid League [BMS06].

The robots we reported here are either intended for or have been used with children, but there are also others. Some were used in the humanoid robots competitions, some are closer to remote controlled toys intended for children.

Most of those platforms were not used in schools over long periods or in a repeated manner. The examples that we saw reported experiences with custom software or material and presence of the scientists throughout the study. For teachers to really adopt this technology, they need to be able to use it autonomously, even without the help of the scientists who conceived the robots. However, we see that the strength of the humanoids is generally to serve as a partner or a tutor. In [HJPK05], they argue that the humanoid robot's ability to move or display facial expression could be a key to enhanced interaction with the user and higher motivation, compared to e-learning techniques on computers. [KHEI04] think that a human shape and human-like behaviour makes it intuitive for users to interact with the robot. They consider however that the technology is premature in certain aspects, and that for example speech recognition should become more reliable before we are able to use robots as tutors.

2.1.2 Kits and modular robots

The most popular robotic kit for children is without doubt Lego's *Mindstorms* [Legc]. This kit has the famous bricks system combined with a central processing block, to which sensor and actuator modules can be connected. The current version, *EV3* (see Fig. 2.2a), allows to connect four sensors and four motors at the same time to the central brick, with different types of sensors and motors available. The central bricks can be daisy-chained to build more complex systems. Since EV3 only came out in 2013, the most used version, both in teaching and in research, was the previous release: Mindstorms *NXT* (see Fig. 2.2b, released in 2006). It features are quite similar with a few differences: no daisy-chaining, one less motor can be connected, fewer sensor choices, a different set of bricks in the package (the differences between the processor bricks are listed in [Xan]. Lego did their best to keep backwards compatibility with NXT. Lego Mindstorms are programmed with a graphical interface derived from National Instruments LabVIEW. In addition they offer a website dedicated to education [Legb], where they offer special kits, pedagogical materials for different age groups, and a community. Lego Mindstorms are also the platform for several robot competitions: Jr. FIRST LEGO League, FIRST LEGO League, FIRST Tech Challenge and World Robot Olympiad. The Roberta initiative also picked this kit as their preferred platform [BL10]. In addition, as reported by [Ben12], 90% of the studies published use Lego robots. This kit is officially aimed at children eight years old and older, and costs around USD 350, depending on the kit version and the country of purchase.

Lego offers a simpler product for younger children (see Fig. 2.2c), the *WeDo* Construction Set [Legd]. The set comes with different parts, including Lego bricks, a motor, a tilt sensor, a

(a) Honda's ASIMO robot (image courtesy of [Hon14]).

(b) e-Nuvo WALK (image courtesy of [ZMP14]).

(c) Gogic Player (image courtesy of www.techradar.com).

(d) Robovie-i (image courtesy of allday.ru).

(e) RB2000, and upgrade of Robovie-i (image courtesy of www.graupner-robotics.de).

(f) Robovie-nano (image courtesy of robot.tsukumo.co.jp).

(g) IROBI (image courtesy of yujinrobot.com).

(h) Nao (image courtesy of servicerobotics.info).

(i) DARwIn-OP (image courtesy of darwinop.sourceforge.net).

(j) Robosapien (image courtesy of www.pcmag.com).

Figure 2.1 – Humanoid robots used with children.

motion sensor, and a USB hub. A computer is necessary at all times, and children can build and program reactive constructions. Only one sensor and one motor can be used at the same time, reducing drastically the possible constructions. The dedicated software also derives from LabVIEW, and includes step-by-step activities. This kit is officially aimed at children aged seven years old and older, and costs USD 130.

Parallax produces the *Boe-Bot* kit [Parb] to teach electronics, programming, and robotics to high school students and older, and to hobbyists in general (see Fig. 2.2d). The kit includes a basic microcontroller board with a breadboard so that no soldering is required, electronic components, mechanical parts, motors and an instructions booklet. Once built, it takes the form of a wheeled robot. It is programmed in PBASIC, and the booklet is meant to make robotics accessible to beginners as young as 13 years old. This kit costs USD 120. In addition to the curricula offered by Parallax on their website, the community around this platform has developed quite a lot of material for teachers [TTS], [Bal08].

The *Arduino* platform is not limited to robotics, and aims to be an easy-to-use base for all sorts of interactive projects [Ardb]. The starter kit (approximately USD 100) includes an Arduino Board (with an Atmel AVR microcontroller), a breadboard, several electronic components, one DC motor and one servomotor, and a projects booklet with instructions to build 15 different projects. Arduino is also open-source and has a strong community, with a forum and a wiki, with many user-contributed translations, included in the main website. Different types of Arduino boards exist, with a variety of processors, memory, I/O ports. They can be programmed through the Arduino environment, the Arduino language being in fact a set of C/C++ functions. In addition to the activities proposed by Arduino itself, many books were written on the topic ([Mar11], [Mon12], [Blu13], [Box13], [Nus13] among others), showing the platform's popularity and adoption by the wide public. Naturally Arduino did not go unnoticed with roboticists and teachers [WAM11]. It has been used in higher education [APCR13], in conjunction with the Boe-Bot platform [Bal10] (see Fig. 2.2e), and was adopted for work with children [Gen14], [ZMB10]. The strength of Arduino is its flexibility and the enormous amount of materials available.

Dwengo is a very similar project (see Fig. 2.2f), with a combination of boards (with a Microchip PIC microcontroller), breadboards, electronic components and an open source philosophy [Dwe]. A starters kit (without electronic and mechanical components) costs around USD 120 and a robot starters kit (including an additional sensor panel and a robot frame) costs around USD 310. The Dwengo organises robot competitions [WHS10] and offers curricula on the website, to teach mathematics and STEM to 11 years old children and older. The community is much smaller than the Arduino community but the principles are very similar.

The *Raspberry Pi* (see Fig. 2.2g) is also a popular board, but this time it is a real computer on which an operating system like Linux can run, contrary to the boards presented above that only have microcontrollers [The]. Developed as a low-cost, credit card sized computer, it can be programmed in accessible languages like Python and Scratch. Like with Arduino, the

Raspberry Pi became very popular and has a huge community of contributors and books were written on the topic [RW12], [HBM+14]. The Raspberry Pi foundation created pedagogical material as well as the Picademy to train teachers. However, though it was originally intended for education, it seems that the board found its place among hackers more than in schools [Gho14]. Apparently though computers were offered to schools with the support of Google and advice for teachers was available on the website, the effort was too big for teachers and they felt lost in the abundance of information.

The *VEX Robotics Design System* (see Fig. 2.2h) offers a variety of motors, structural and motion elements, sensors, processing units to build custom robots [Vex]. It is an official platform for the FIRST Robotics Competition. Teachers have their own line of products, VEX IQ, with starter kits costing USD 250 and a free curriculum to teach STEM to eight years old children and older. Components are also sold separately. The kit is appreciated for the variety of parts it offers and its flexibility, and is often used in competitions or in education, combined with other technologies [CM09], [Car11].

Fischertechnik (see Fig. 2.2i) produces several kits with a similar abundance of structural and motion parts in addition to the sensing, actuating and processing elements usually found in robotic kits [Fis]. With the Lego Mindstorms and the Vex kits they are among the most popular platforms in schools [Kee11]. Fischertechnik has robot kits with different applications, educational materials to teach STEM, and a dedicated graphical programming software called ROBO Pro.

Robotis' *Bioloid Premium* (see Fig. 2.2j) is a kit composed of 18 servomotor modules, sensors (gyroscope, IR receiver, distance sensor), a battery, mechanical parts, a controller board and a remote controller, sold at USD 1'200 [Rob]. Users can build different shapes: humanoid, dinosaur, puppy, spider, scorpion. A special software (RoboPlus Motion) allows to program motions, otherwise C language is supported. It comes with an instructions booklet. This platform resembles more the humanoid platforms of the previous section, with the difference that several models can be built. The accent is again on the motions of the constructions and on programming sequences of movements.

Modular Robotics' *Cubelets* [Mod14a] are cubic modules with different functionalities that can be assembled thanks to a magnetic fixation system to build robots (see Fig. 2.2k). No programming is involved and several kits are available, with prices ranging from USD 160 to USD 1'000. The system aims to introduce STEM children aged four and older through discovery by experimentation. A pilot experiment in high schools showed, after a one-hour curriculum, improved understanding by the pupils of the role of scientists in the creation and operation of robots [CWS]. Modular Robotics also has another kit, *MOSS* [Mod14b], for children aged eight and older. This one allows for programming with Scratch (see Section 2.2.1) or in C code.

The *ToPoBo* (see Fig. 2.2l) kit does not need programming either, and is meant to allow exploring the topology of kinematic systems [ToP]. The kit consists of passive and active elements, which can memorise and reproduce a movement performed by the user. By combining all elements the user will build kinematic structures. There is no sensing involved. Some more complex modules, called queens, can control the active modules. A basic set costs USD 150, but only a prototype series is available for the moment. The kits were used with children as young as four, more in an open-ended, play activity than inside the curriculum [PRI08]. Sufficient time seems to be a critical criterium for the child to engage properly with the kit; in addition the teacher needs to be familiar with the platform.

Those are in our opinion the most significant examples of robotic kits for children, but more exist. We can already see with this sample that there are different directions and interests among them. Kits and boards often put an emphasis on the electronics and allow to introduce how circuits are built, as well as making completely customised systems, ideal for robot contests. In that case the system flexibility is greatly appreciated. The kits most accessible to young children do not involve electronic design, and sometimes not even programming. If programming is present, it is generally in the form of a graphical language.

2.1.3 Wheeled robots

Wheeled robots provide a cheap, simple solution in many contexts. They have some advantages compared to legged robots. To follow a certain path on a flat surface they only need two motors for the wheels while a humanoid will have a more complex actuation, thus a higher chance of having a problem, and need to keep their balance. In education, wheeled systems can be used to learn about basic control, embedded programming or artificial intelligence.

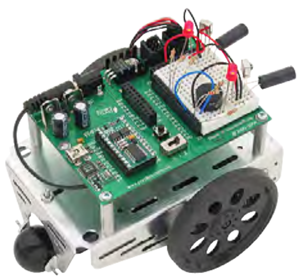
IRobot *Create* (see Fig. 2.3a) is an affordable platform at a price of USD 130 [iRo]. It closely resembles iRobot's famous vacuum cleaner Roomba (see Fig. 2.3b), without the cleaning system. Instead there is a cargo bay and space for the iRobot command module (discontinued) or the user's own electronics. Without command module the robot's actions can be programmed via a serial port from a computer. Its low cost remains it main advantage, and while it may not be usable as-is by very young children, materials for elementary schools have been developed on this platform as well as on the Roomba, in combination with a Gumstix to enhance the computing capacities [MKFS07]. The goal was to bring STEM introduction to young children. Other projects using the iRobot Create also combined it with other materials for computing and sensing capacities [LBJ+08], [LFL+09]. Those initiatives remain limited in impact and required the presence of the experts during the experiments.

Parallax, who produces the Boe-Bot kit, also proposes the *Scribbler* (see Fig. 2.3c), a small wheeled robot that comes with pre-programmed behaviours and has two wheels, infrared sensors, and a hole for a pen [Para]. It can also be programmed through a graphical language or a BASIC-like language. It costs USD 100. Where pedagogical materials have been made available, the platform was adopted by schools [Dem08].

(a) Mindstorms EV3 (image courtesy of firstlegoleague.org).

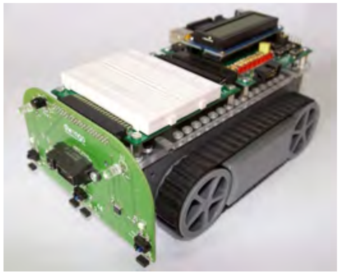
(b) Mindstorms NXT (image courtesy of firstlegoleague.org).

(c) WeDo (image courtesy of www.legoeducation.com).

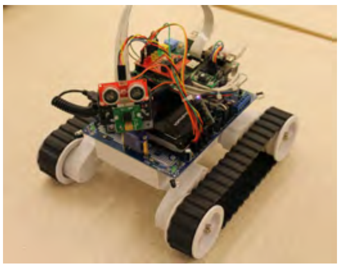


(d) Boe-Bot (image courtesy of [Parb]).

(e) Robot built with an Arduino board and a Parallax shield (image courtesy of www.adafruit.com).



(f) Robot built with a Dwengo board (image courtesy of [Dwe]).



(g) Robot built with a Raspberry Pi (image courtesy of blog.dawnrobotics.co.uk).

(h) VEX Robotics Design System (image courtesy of [Vex]).

(i) Fischertechnik system (image courtesy of [Fis]).

(j) Bioloid Premium (image courtesy of [Rob]).

(k) Cubelets (image courtesy of www.hizook.com).

(l) ToPoBo (image courtesy of www.hayesraffle.com).

Figure 2.2 – Robotic kits and boards.

K-Team has produced several educational platforms over the years, some of them accessible to a young public. The *Hemisson* (now discontinued) was a low-cost version or their famous Khepera [MNS08a], had a wide array of sensors and the possibility to add extensions. It cost around CHF 350 and was intended for high school age users. K-Team now proposes the K-Junior (see Fig. 2.3f) for CHF 750, also a wheeled robot with an array of sensors and possibilities of extensions [KT].

The *Bee-Bot* (see Fig. 2.3d) by TTS targets specifically very young children (from five years old) with a design resembling a bee [TTS11]. Not programmable, it has simplistic features: two motors with encoders, buttons, lights and a speaker. It costs around USD 80. Without sensing capacities, it is not meant to introduce STEM or technology to children, but to teach principally other topics, with the help of adapted game mats. Its popularity come from the amount of pedagogical materials available, both on the producer's website and made by teachers (for example [Aub11]. Several programs in schools chose this platform and the teachers themselves are confident in using it [Jan08], [DDS08], [HMH08]. TTS also produces *ProBot* (USD 140) with a similar principle, but with more buttons and an LCD screen to give a possibility to program in LOGO language (see Fig. 2.3e).

In Japan, Vstone offers the *Beauto* series with *Racer*, *Chaser* and *Balancer*, for prices varying between USD 38 and USD 112 [Vst14], [BLMM13]. Racer (see Fig. 2.3g) and Chaser (see Fig. 2.3h) are quite similar, simple two-wheel car-like robots, the latter being the more complex and computationally powerful, while Balancer (see Fig. 2.3i) is in fact an inverted pendulum. All three can be programmed through the dedicated block flowchart interfaces Beauto Builder R, Builder NEO and Balancer Programmer, but only Chaser and Balancer support C programming. The target audience for those three platforms range from primary school to university, and the aim is principally to teach control.

ZMP also has a platform to teach control systems (see Fig. 2.3j), the four-wheeled robot *e-Nuvo Wheel* [ZMP14]. Much more complex and advanced than Vstone's platforms, option packs also allow to teach inverted pendulum balancing, and the basic package already costs USD 1'180 [BLMM13]. With such characteristics, it clearly targets more the university level education.

Some kits allow to build wheeled robots (see Fig. 2.3k), with or without soldering, like Elekit's *MR-005* and *KIROBO MR-9132* [BLMM13]. They are presented in this section because even though they are kits, they do not really allow for modularity or customisation. Intended for children older than 12, their low price make them very accessible for pupils (between USD 25 and USD 50). The programming is done through Elekit's icon-based flowchart software.

KIBO (previously KIWI), a wheeled robot for children developed by TUFTS university, also need some assembling but no soldering or electronics knowledge [Kin]. This platform aims for a more creative than technical image, and promotes crafts materials for constructions. Its hull itself has wood instead of plastic and metal (see Fig. 2.3l). It is programmed with wooden blocks, thus no computer is needed. Pedagogical materials are also proposed on the website. Kits cost between USD 230 and USD 400.

There are also examples for educational robots aimed at the university level, like the Khepera ([MFG99]), the Pioneer ([Mob12]), or the Turtlebot ([Gar11]), but they are often not used with children. We will however mention work done with the *e-puck* robot, developed by EPFL, in Section 3.4, and explain its influence on our work.

With all these examples we see that, for wheeled robots, the key feature is often "low cost". Their applications are quite varied and age targets change with the platform. Still, very often, the first notion put forward is control, very close to the sensor-actuator loop that we mentioned previously. In the next section we will discuss a bit more in details the links between the shape and usage of the robots.

2.1.4 Link between the robot's morphology and its role

After seeing a number of examples of robots used in education, we start to see a pattern between their characteristics and the role they have, as well as the topics taught.

With humanoid robots, the interesting feature for education seems to be their expressivity and capacity to sustain a social interaction with the users. Thus they are often used in the case of a tutor robot or a peer robot. For programming, simplified softwares generally allow to prepare choreographies. However, more complicated programming with reactive behaviours, as would be necessary in a robot competition, is too difficult for young pupils, because of the inherent complexity of the dynamics involved to control walking bipeds. As described in [Ben12], humanoid robots are most generally a "non transparent technology"; users do not understand the inner functioning of the robot. There are however dedicated robots competitions for humanoids.

Kits often involve soldering or assembly of electrical components, thus they are used in electronics or embedded programming courses. In this case they are more in the role of an object of study, or that of a tool. Their other advantage is their flexibility, thus they can be used to create different types of animated or reactive systems, giving a bigger place to imagination and creativity. Because of this, they might be adopted as a base for collaborative projects, and to develop transversal skills. The construction aspects fit particularly well in Papert's constructionist philosophy. Many hobbyists have adopted them and they can serve as rapid prototyping platforms for interactive systems. Open-source systems are popular and generate big communities. The downside is that they are less accessible to young children when the low level programming and electronics have to be taken care of. Some kits are simplified to get rid of the electronics and have beginner-friendly graphical programming interfaces like Lego's products. Others get rid of the programming on a computer itself like Cubelets and ToPoBo, letting young children explore the construction and topology of such system through play. However, learning this way and exploring shapes takes time, which is not always available in classes. High school teachers for example told us that they kept their Mindstorms in a single configuration to gain time.

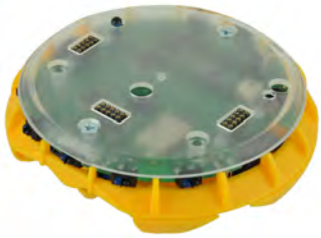
(a) iRobot Create (image courtesy of www.robotshop.com).

(b) iRobot Roomba (image courtesy of [iRo]).

(c) Scribbler (image courtesy of [Para]).

(d) Bee-Bot (image courtesy of [TTS11]).

(e) ProBot (image courtesy of [TTS11]).



(f) K-Team K-Junior (image courtesy of k-team.com).

(g) Beauto Racer (image courtesy of www.seeedstudio.com).

(h) Beauto Chaser (image courtesy of [Vst14]).

(i) Beauto Balancer (image courtesy of [Vst14]).

(j) e-Nuvo WHEEL (image courtesy of techon.nikkeibp.co.jp).

(k) KIROBO MR-9132 (image courtesy of www.bukalapak.com).

(l) KIBO (image courtesy of [Kin]).

Figure 2.3 – Wheeled robots for children.

Finally, wheeled robots are often picked for their low price, as a ready-to-use robot that is quite easily controllable. Their advantage over kits is the gain of time, they are directly functional, sometimes with pre-programmed behaviours. For teachers, it might also seem like a better first step into robotics, because it is possible to start with the high-level features. They are often used to teach basic notion of control. Their role is that of an object, or a tool. For very young children, programming with a computer might not seem adequate; thus the Bee-Bot for example uses a button interface.

Based on these observation it seems clear that we are far from having a universal robot for education; in fact there is a multiplicity of platforms, with different pedagogical objectives and age targets. Adaptation for the young public often means removal of features, and specialised materials and programming interfaces. Programming also is obviously linked to educational robotics, while electronic and mechanical aspects can be more easily set aside. In the next section we will take a look at programming interfaces designed especially for children.

2.2 Programming interfaces for children

To make programming -and robotics- accessible to young children several factors must be taken into account. First, if we want to concentrate on central concepts, it is often preferable to get rid of low level constraints that make understanding more complex. For example, to use a sensor, pupils should not have to wonder which kind of microcontroller they are using, on which pin the sensor is connected, or how the communication is done. They should be able to concentrate on the information the sensor is returning, and how to use it in a behaviour. A teacher who wants to start with programming might also find it convenient to avoid having to install many specific libraries or picking the right configuration. Because of this, programming interfaces for robots are generally customised for one specific model. Specific functions represent the hardware's different features, or particular commands. For example, in a humanoid robot programming interface, there will generally be a graphical representation of the robot, and libraries will be available with functions or name designating features not by technical words like *motor_1*, but recognisable names such as *right_elbow*.

The second key point is language, and ability to read. Standard programming languages are based on inputting text with a certain syntax, and with keywords representing commands, code structures or hardware features. Those keywords are in English in all standard languages. In Switzerland, children start to read around the age of seven, and not all even study English at school. Furthermore, they are not comfortable with big chunks of text before a few years of study.

Finally, to program a robot, a computer is generally used. Using keyboards and mice, being comfortable with launching programs and navigating through OS should not be taken for granted with children. This can also influence the programming interface used by children.

We will have a quick look at existing programming interfaces and languages for children. Some use text like standard languages, others use visual cues and icons to represent a program, finally some attempts have been made to avoid using a computer altogether.

2.2.1 Text-based Interfaces

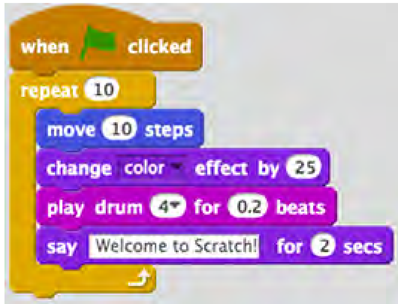
Text-based interfaces are the current standard for programming languages. They are however not especially beginner- or children-friendly.

In Italy, in order to make programming more accessible to children, researchers from the university of Torino developed *NQCBaby* [Dem08], a mini language based on *NQC* (Not quite C [BH03]). NQCBaby offers limited functions, as it is not meant to turn children into advanced programmers, but rather to let them solve problems with the algorithmic principles of programming. The language is mother-tongue based, and uses child vocabulary instead of technical words (see Fig. 2.4a). It has different levels of complexity, each level being completely included in the next one, allowing for a progression. The lowest level in this concept is iconic, with icons corresponding to the buttons on the Bee-Bot's back (forward, backward, left, right), for children who cannot read yet. When progressing children will use different platforms, Bee-bot, Scribbler, Mindstorms RCX and NXT. The NQCBaby code is then translated into a language compatible with the used platform. This language has been successfully used in italian schools with about 1'000 children aged from five to thirteen [DDS08].

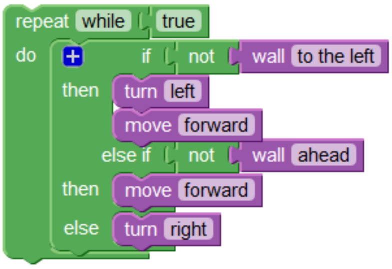
Scratch (see Fig. 2.4b), developed by the MIT Media Lab, has many graphical aspects, but still retains text on all the blocks [RMMH$^+$09], thus we kept it in the text-based category. It is originally not specifically intended to program robots, but sprites and animated characters. There are, however, extensions that allow to connect to robots. For example, the *Enchanting* environment is a variation of Scratch for Lego Mindstorms [OP14]. Scratch offers puzzle-like programming blocks, sometimes with adjustable parameters, that are assembled to create behaviours. The blocks' functions are given by text; Scratch is translated to several languages to adapt to different countries. Block colours and shapes help differentiate between conditions, commands, control structures and so on. The shapes also prevent syntax errors, as ill fitted blocks will not connect. It is also interesting to note that commands are grouped by events, making it an event based language, though there is a hidden infinite loop and sequential execution of commands.

Google *Blockly* [Goo] and *ArduBlock* [arda] follow the same puzzle-like approach (see Fig. 2.4c and Fig. 2.4d). Blockly is in fact not directly aimed at programming robots, but rather lets the user create custom blocks for his own goal. They can be then used to create programs. ArduBlock is a plugin for the Arduino IDE. Blocks represent the functions of the Arduino libraries, as well as common Arduino components like joysticks. Both ArduBlock and Blockly then translate the code into another language (Arduino Language for ArduBlock, and a language depending on what the user designed for Blockly). This can be convenient as a first step into those languages [VSCV13].

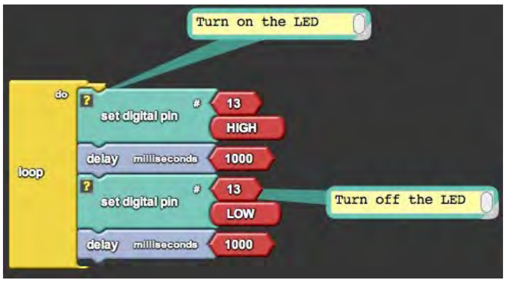
(a) Example of NQCBaby code (image courtesy of [Dem]).



(b) Scratch (image courtesy of scratch.mit.edu).

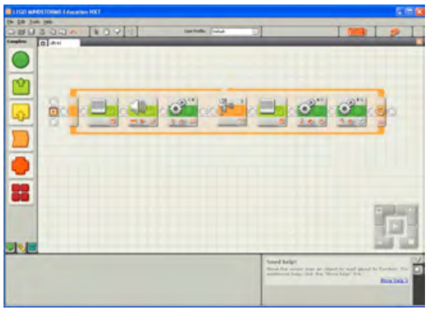


(c) Blockly (image courtesy of www.quora.com).



(d) ArduBlock (image courtesy of blog.ardublock.com).

(e) Scratchjr (image courtesy of ase.tufts.edu/devtech).



(f) Lego Mindstorms programming environment (image courtesy of shop.educatec.ch).

(g) Lego WeDo programming environment (image courtesy of [Legd]).

(h) CHERP (image courtesy of ase.tufts.edu/devtech).

Figure 2.4 – Programming interfaces for children.

2.2.2 Graphical programming languages

Graphical programming languages aim at making the programming more intuitive and understandable by using logos and visual cues instead of text. Some of them retain text for some aspects, for example for a variable value, or a parameter, but overall the amount of text is limited, making it more accessible for young children who are not very comfortable with reading.

ScratchJr (see Fig. 2.4e), an adaptation of Scratch for children aged five to seven, keeps the puzzle-like bricks but gets rid of the writing [FSK+13]. The principles are the same as with Scratch: different characters can be animated, small sequences can be assembled from blocks, and associated with events. Almost everything is represented with logos and arrows, and there are very few words and numbers left. Development is not over yet, but the first results are promising: children manage to differentiate between the different types of blocks, create and customise characters, use the *motion*, *sound* and *looks* actions, use the *end* and *repeat forever* instructions. They found it more difficult to coordinate different characters' actions, understand more abstract commands, determine appropriate numeric parameters for certain actions or develop problem-solving strategies.

The Lego softwares for the Mindstorms kits (see Fig. 2.4f) are based on LabVIEW [Lege]. Programs are created by assembling icons in a sequential way, with the possibility for more advances flow control like loops and conditions. All sensor and action blocks are adapted to the Lego hardware, thus the language cannot be used for another platform. The software for WeDo (see Fig. 2.4g) uses similar icon-based sequences, but integrates step-by-step tutorials with animations, exercises and solutions [Lega].

2.2.3 Tangible programming

Tangible programming aims at freeing the programming from the computer to come into the hands of kids. They generally take the form of blocks that can be assembled, much like construction toys. The most basic form of tangible programming, however, is the button interface, like for the Bee-Bot where a sequence of movements can be memorised, or the Robosapien's remote-controlled movements.

When designing a tangible programming language with physical elements that represent computer science concepts, several questions arise. How to capture, compile the code and then transmit it to the robot? How to determine, of all elements on the work surface, which ones should be taken into account and which ones are not meant by the user to be part of the program? When is feedback, such as compilation errors or parameters change, to be given, and how? While not many platforms are commercially available, a lot of research is in progress on the topic. Very often, the programming elements are blocks with text or images, not active by themselves, but with a camera monitoring the work surface [HJ07]. *Tern* and *Quetzal*, designed to control simulated robots and Lego Mindstorms respectively, use blocks with text that connected together for sequences of instructions, with possibility of loops and subroutines. Such interfaces should be more inviting for children, looking voluntarily like construction blocks, sometimes using wood, and should promote a collaborative approach as they are more accessible than a computer interface with a single input system. Tested in a museum compared to a graphical interface, the tangible approach was more inviting, more child-focused and indeed provoked more collaboration [HSCJ09]. Sometimes, projectors are used to give feedback or display information [GJJ08], [BPD10]. Some systems integrate electronics and thus computing and feedback functions directly into the blocks [ZAR05]. This removes the need for a computer altogether but makes the cost of a single block much higher and compromises its robustness when manipulated by kids. Overall many questions are still not answered and we should be careful when designing tangible interfaces to take several aspects into account, like how an object is to be represented, how the interface influences a certain cognitive process. Design aspects are closely linked to the learning outcomes, and need to be evaluated correctly for each pedagogical objective [CJD12]. Making a task easier does not necessarily mean the learning will be improved.

One commercially available system, *CHERP* (Creative Hybrid Environment for Robotic Programming), is based on wooden blocks that are assembled together [Dev]. On each block, a logo represents a function, value, or element of a program. Each block is identified by a barcode than can be read by the KIBO robot, or interpreted by a computer after taking a picture of the program (see Fig. 2.4h). An equivalent computer-based interface, featuring the same logos, also lets users create or modify programs. In addition to the KIBO, CHERP can be used with Lego WeDo. This interface is more sequential than event-oriented. A pilot study hints that tangible interfaces might help in the comprehension of abstract concepts like repeat loops [SB14].

Sometimes tangible programming is embedded within the construction kits, like with ToPoBo and Cubelets. Such configurations have a strong link between the function and its embodiment, and it makes it difficult to integrate concepts like loops and conditions. For example building a stable, walking structure might be difficult enough without adding a condition that would create a physical fork in the robot's body. In the Electronic Blocks project, researchers noticed that children had trouble understanding and using the logic elements as opposed to action or sensing blocks, and complexity of programs did not emerge in the expected way: children created interactions between different assemblies rather than building one complex system [WW01].

2.2.4 Conclusions

In the examples above we see a strong link between the programming language and the hardware used. In order to be adapted to children, the low level constraints are set aside to concentrate on programming at a higher level: animations, behaviours, reactivity. Because of this the instructions become closer to natural language, take names or graphical representations of actual elements of the kits, thus becoming specialised and platform-dependant.

Visual cues in drag-and-drop interfaces help children to understand the different concepts. Text can be mostly removed in graphical programming languages, which allows to reach very young children, before they can read with ease. However, the computer itself can become an obstacle, as not all children are confident with it, and not all classrooms are equipped with one.

Tangible programming could help with this aspect, as well as promote collaborative work. A lot of research is done on the topic, but few platforms are available commercially. Tangible interfaces are still very young, and many questions should be addressed before we fully understand their impact. In parallel, new technologies like tablets and smartphones also change the way in which we use ICT technologies, and could bring new solutions to creating programming interfaces for children.

2.3 Impact of the robots in classrooms

We saw in the previous chapter that there are a lot of expectations pertaining to educational robots. There is also a variety of available platforms. We will now take a look at the actual results: are those kits efficient tools to teach? What is their penetration in schools?

As reported by [Ben12], there are actually few studies that present conclusive research on the topic, with true experimental design. Most of the literature on robots for education is descriptive in nature, reporting the design of platforms or activities, and providing not much more than reports of the enthusiasm of the users in pilot studies. With quite selective criteria, only 10 papers were left for Benitti's systematic review. Among the 196 papers found with the research keywords, 31 were excluded because the courses reported aimed at teaching robotics, 60 because there was no quantitative results, 90 because the context was not in an elementary, middle or high school, and 5 because it did not show the use of robots. It is especially revealing that so many papers about robots and education actually cover undergraduate or graduate levels of education. Teaching outside of university context brings new constraints, such as fitting in the curriculum, training teachers, having the materials available. Out of the selected ten papers, we should note also that in nine cases Lego platforms were used, and the topics taught were mathematics (5), science, engineering and technology (5), thinking and process skills (3), social skills (1) and basic principles of evolution (1). The sample is really narrow in the types of platforms used and topics taught remain focused on STEM. Benitti concludes that from the selected articles, we cannot argue that the use of robotics to teach STEM necessarily benefits to students learning, but progress was noted in some cases. For the development of skills such as thinking skills, problem solving skills or social interaction skills, results are absolutely inconclusive. Finally he assumes that robotics have tremendous potential to assist in teaching, however the simple application of robotics to a course is not sufficient.

The review also summarises a few important points mentioned in the papers it covers. Several of them [HLS06], [LH07] emphasise the role of the teacher and his considerable influence on the pupils' achievements. This is supported in the literature, by [Tho09] and [VRW07] who state the teachers should be skilled in the technology used to obtain benefits, and that sufficient training is needed for the teachers to feel comfortable and to answer their student's questions. In such studies, teachers themselves generally request support. They want to be taught usable examples, need ready-to-use teaching materials [PRI08]. Other important points are raised on the setup in which the pupils work: it's important to work in small groups of 2-3 pupils and to have a large space to work [LH07], pupils should have a chance to explore the robotic kits before working a design challenge [WMPF07], and the robotics environment should be rich in tools, have immediate feedback built into the system in order to result in the use of thinking and science process skills [Sul08], as well as the open ended nature of the student enquiry.

In [GZ13], a preponderance of qualitative studies over quantitative ones, and the omnipresence of STEM as a topic, are similarly noted. They consider this as the sign that the field is still new, and there is a need for literacy phase before teachers can master this technology, but they see a great potential in educational robotics. Qualitative methods are likely chosen because the crucial parameters that can be evaluated in quantitative studies are not yet well identified. They also highlight the fact that the technology itself cannot have an impact on the learning outcomes, it needs to be appropriately orchestrated depending on the desired pedagogical objectives. They raise interesting questions on the role of the teacher in these new ventures, which shifts from dispensing knowledge to becoming a mediator between the children and the robots, the pupils' ideas and their feasibility. They warn against using such technologies just because they exist, and remind of teachers' right to choose their own pedagogy. They suggest that new pedagogical methods and new evaluation methods of their effects need to developed conjunctively, which is hard to achieve.

Overall in the literature we find few long term studies, for several reasons: as mentioned above, it might be too early and robotics curricula are not yet in place, or teachers are not familiar yet, and affordable, abundant materials has not yet arrived. The question left open by this is whether the enthusiasm often mentioned is just a novelty effect. However there are reasons to think that interest in robotics can be maintained over longer periods, like in the Piedmont PIONEER initiative [DDS08].

Benefits such as increased interest in technical studies and transfer of knowledge to other areas can only be thoroughly assessed once longer-term use or robots in classes actually happens. In addition, a number of trials are likely to be necessary before having the right tools to measure the impact on learning. It is currently extremely difficult to create a long-term experimental setup with a valid control group and one isolated factor because we lack experience. For example, in [FM02], an experiment destined to measure the impact of using robots for college programming lessons instead of a computer interface produced unexpected results. While the authors expected equivalent or better score at the final exams, and higher motivation to pursue this orientation for students who had used the robots, the exact opposite happened. The students who had to do their assignments on robots were less motivated by the branch and performed worse. After holding a focus group to understand the cause of this result, it appeared that students had only limited access to the robots during certain periods of the week, while those who had to program a computer interface as assignment could work on their own laptops during their free time, ending in the robot users being unable to work efficiently and becoming disgusted. Overlooking this factor was a serious mistake, and a seemingly well planned experiment was spoilt because of it.

Measuring the transfer of the knowledge acquired when using robots is also a tricky question. An interesting attempt was made in Japan, where two groups of pupils were asked about their understanding of a technology-related accident [KKKK07]. Their goal was to evaluate whether having studied a bit of programming robots improved the pupils' technological literacy. It seemed that those who had studied the robots were more confident in explaining the incident involving a faulty elevator and could see a common point between the technical systems, while the other group lacked this literacy.

Many reports of the robots' educational benefits focus on competitions [PP04], [SEJ03], but the problem is that this type of activity might attract only a specific category of participants. Other strategies, that focus more on collaboration and creative storytelling than on competitions and technical construction, might appeal to a wider category of children [RRBPG08]. For example it seems that competitive events do not particularly appeal to girls [LTEP99].

While there are many available platforms and abundant research, we also see that teachers themselves are still starting to adopt robots. The popularity of Lego products and of the Bee-Bot indicates that commercial availability plays an important role in the teachers' choice, and the abundance of pedagogical materials forms a great incentive. Teachers want to know where to start and need guidance [BPJ+02]. Their experience and inputs are also crucial and they should not be forgotten when designing robots and corresponding curricula. The research on educational robots generally concentrates on the child-robot relationship, but the teacher should be integrated into the model and taken into account if robots are to enter schools. To evaluate the teacher side of the problem, one cannot rely solely on pupils' results. We need to understand their motivation or reluctance to use robots, and the robot's pure efficiency or utility as a teaching tool is not the only factor to be taken into account. Usability and acceptability, along with utility, have been proposed as dimensions in the evaluation of intelligent tutoring systems [TPSC+03].

- The *utility* represents the adequacy between the learning objective defined by the teacher, and the success in reaching this objective.
- The *usability* indicates the possibility to use the technology, its ease of use.
- The *acceptability* accounts for the mental representations of a learning technology, the opinions and attitudes toward the technology, its utility and usability. More concretely,

acceptability can become an obstacle to the adoption of a technology even though it is useful and usable. For example, if a teacher considers it is not adapted for children because it looks too complex, or because it seems dangerous, and will not try it despite other positive results.

A similar approach could be taken in order to evaluate robots as pedagogical tools, and in turn help move out of the literacy phase.

2.4 Lessons drawn for this work

We have seen many examples of robotic platforms for children, at different ages, and observed that their form and type highly depends on the teaching objectives and the role assigned to the robot. We also noted that for a robotic platform to be accessible to children, the adaptations were generally to drop low level aspects to concentrate on high-level, experienceable features such as behaviour, interactivity, and construction in a simplified manner (Lego bricks, toy-like construction, customisation with crafts materials). Electronics, assembly of the systems and low level programming are set aside. In addition, eliminating the text as much as possible from the programming interfaces opens the experience to children who cannot yet read with ease.

From our observations in the French-speaking part of Switzerland, and from what we found in the literature, the most widespread platforms in schools are the Bee-Bots and the Lego kits. We consider however that those platforms are not suitable to teaching programming or introducing the sensor-actuator loop to young children. The Bee-Bot is overly simplified and does not retain any sensors but the wheel encoders, that are not visible. The Lego Mindstorms is successful but expensive and considered more adapted in high schools than in primary or elementary classes. The Lego WeDo fits more with this age category, but we consider the limitation to one sensor and one motor as too restrictive. In addition, having the computer as the processing unit of the sensor-actuator binds the children to the desk.

On the current evaluation of the efficiency of such tools, we saw that while they are considered promising, quantitative evaluation with a complete experimental setup is lacking. This can be explained by the fact the field is still new, and there is a need for a literacy phase. During this phase it is crucial to involve the teachers, and not to just concentrate on the child-robot relationship, but to take the whole child-teacher-robot triangle into account.

For our own enterprise we will try to study these different aspects in parallel. We aim at developing a robotic platform that appeals to a wide public and is an accessible technology even for young children, without over-simplification. We will take into consideration also the teachers' concerns such as the cost and flexibility of the platform. For the evaluation, we will consider not only the utility, but also the usability and acceptability of the platform.

In the next chapters, we will describe our own venture into the domain of educational robotics. We will first cover our previous work in the domain, and explain how it led to the requirements list for our robot, Thymio II. We will then give the details of its conception, for both the hardware and the software parts, before we move on to the different user interfaces available. The impact of Thymio II on the public will be analysed and its different aspects evaluated, before we finally conclude and give an outlook on the future of the project.

3 History and Motivation of Thymio II

In this chapter, we will describe our laboratory's previous experience in the domain of educational robotics. We will explain how we came up with the requirements that resulted in the creation of Thymio II. It had influence from different projects, and contributors from different disciplines with complementary points of view. Our laboratory had experience in university-level educational robotics, as well as a long-going collaboration with écal (école cantonale d'arts de Lausanne[1]) designers to explore innovative concepts. The EPFL Robotics Festival brought an encounter with the public, and we also had a chance to receive a market-oriented view from the HEIG-VD (School of Engineering and Business Vaud) specialists. This resulted in rich exchanges of ideas that gave us a good idea of what we could develop successfully.

Three robots that were developed by the group in this context will be described in this chapter: the Robokit, the first Thymio, and the e-puck. The author of this thesis took part in the development of the first Thymio from the prototyping phase to the production stage and first workshops with the public. She then supervised its evaluation and the definition of objectives for Thymio II.

3.1 Initial concept

Thymio II is the result of the combination of different influences and projects. The Laboratory of Robotic Systems (LSRO) had for several years been involved in developing robots for education, albeit not targeting specifically children. The e-puck robot [MBR+09] served as a learning media at the bachelor and master level in the microengineering cursus. A simple philosophy guided the development of this robot: to develop an affordable robot for universities that should have enough sensors to consistently serve as a support to learn embedded programming, signal processing and robot control, and be small enough to fit on a desk next to a computer. The e-puck succeeded in all this; many universities use it for research and teaching.

[1] http://www.ecal.ch

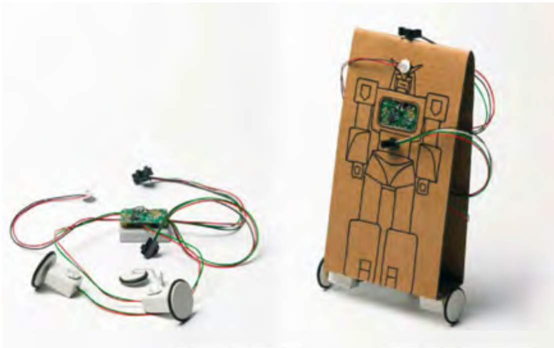


Figure 3.1 – The non-functional prototype by Nicolas Le Moigne & Julien Ayer from écal, demonstrating the new robot concept and its packaging.

In parallel, the group's activities also developed towards outreach events for a young public. In 2008, the first Robotics Festival was held at EPFL. Many workshops offered training sessions or initiations in various robotics-related domains like electronics, programming, soldering and construction.

Finally, the group kept contact with designers of écal to explore novel ideas and collaborate in interdisciplinary approaches. Thymio II was born from these different influences and interests of the people involved in the laboratory.

3.1.1 Workshop with écal

The first idea of Thymio came from a workshop between engineers of EPFL and students of écal. During this workshop, teachers and students from écal collaborated with engineers from the LSRO in order to find new ideas for robots. Nicolas Le Moigne and Julien Ayer came up with an idea for a robotic kit. It was inspired by the well-known toy *Mr. Potato Head*[2]. In this game, children receive cartoon-like body parts and face features that can be pinned into a potato to create a character.

Similarly, the robot kit would contain several modules, some with sensors, some with motors. All were connected by cables. The users would then only need to build the robot as they like, around the support they choose. Anything could become the body of the robot, for example a potato as in the original toy, or even the packaging of the kit itself. A non functional prototype demonstrated the concept (see Fig. 3.1).

3.1.2 The first prototype: Robokit

The LSRO decided to test the concept and built fifteen prototypes named Robokits. Very simple modules made of bare Printed Circuit Boards (PCB) composed the kit: one battery

[2]http://www.hasbro.com/playskool/en_US/mrpotatohead/

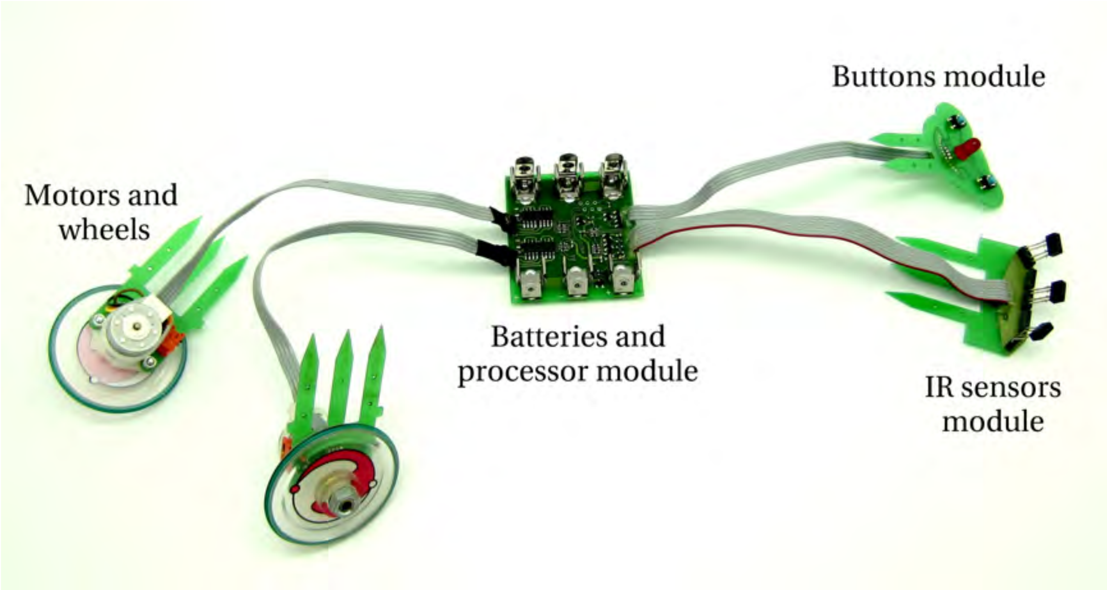


Figure 3.2 – The five modules of the Robokit, connected with cables.

module, two motor-wheel modules, one infrared sensor module and one buttons module (see Fig. 3.2). Pedagogically, this physical separation of functions into modules allowed to highlight the essential elements of a robot. Sensors, actuators, power and processing unit form the base of a system with a sensory-motor loop. Building the robot and understanding the importance of each module gave the children a first insight into robotics, and consequently into technology. The shape of the PCB formed pikes allowing to pin the modules into soft materials. The robot's only possible behaviour was to follow a black line on a white sheet, the buttons serving to start and stop the motors. Thus, it was crucial to place the wheels and sensors correctly and to check whether the cables were correctly connected for the robot to function.

Those kits were used in several handicrafts workshops with children at different occasions: for example during class visits or the first Robotics Festival in 2008. Participants would build a robot using different materials and the kit. They could then test it on a track (see Fig. 3.3). Children loved them, but as there were only a limited number of those kits, the organisers had to take the robots apart at the end of each session to reuse them with the next group, causing huge disappointment. This led to the decision of developing a new version of this kit, that would be easy to use, produced in a large quantity, and respect the safety regulations for toys, so that it could be distributed to participants in the workshops. The first Thymio was born.

Figure 3.3 – During the workshops, participants would build their robot and test it on a track (photograph by Alain Herzog).

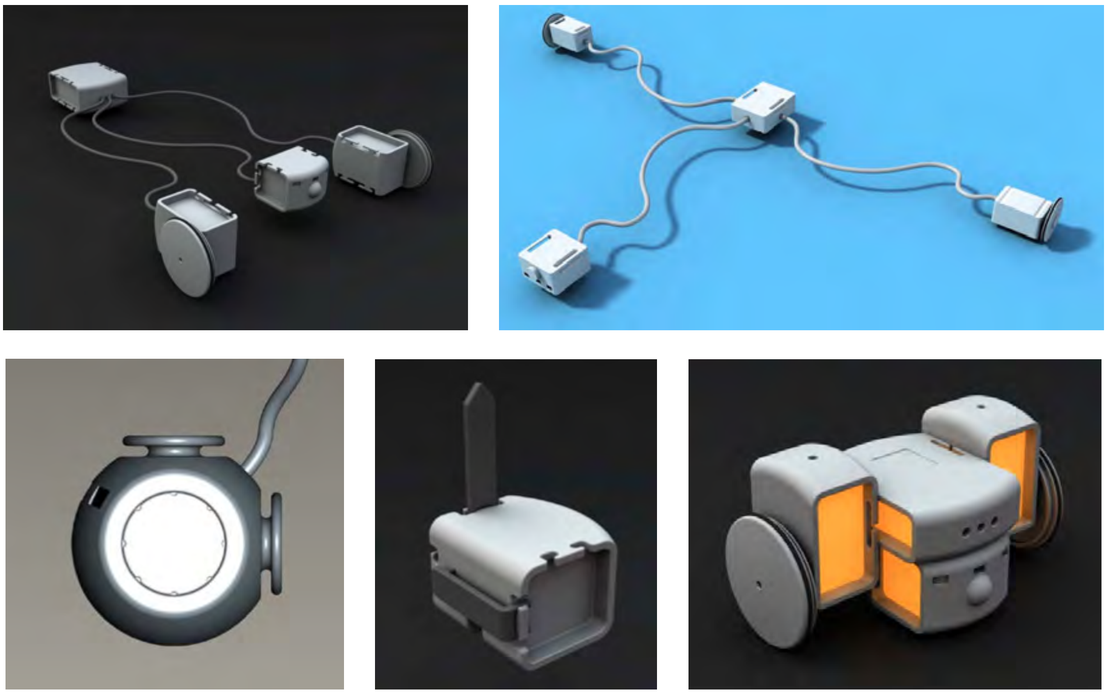


Figure 3.4 – Different shapes were tried for the cases around the modules (design by Julien Ayer & Luc Bergeron).

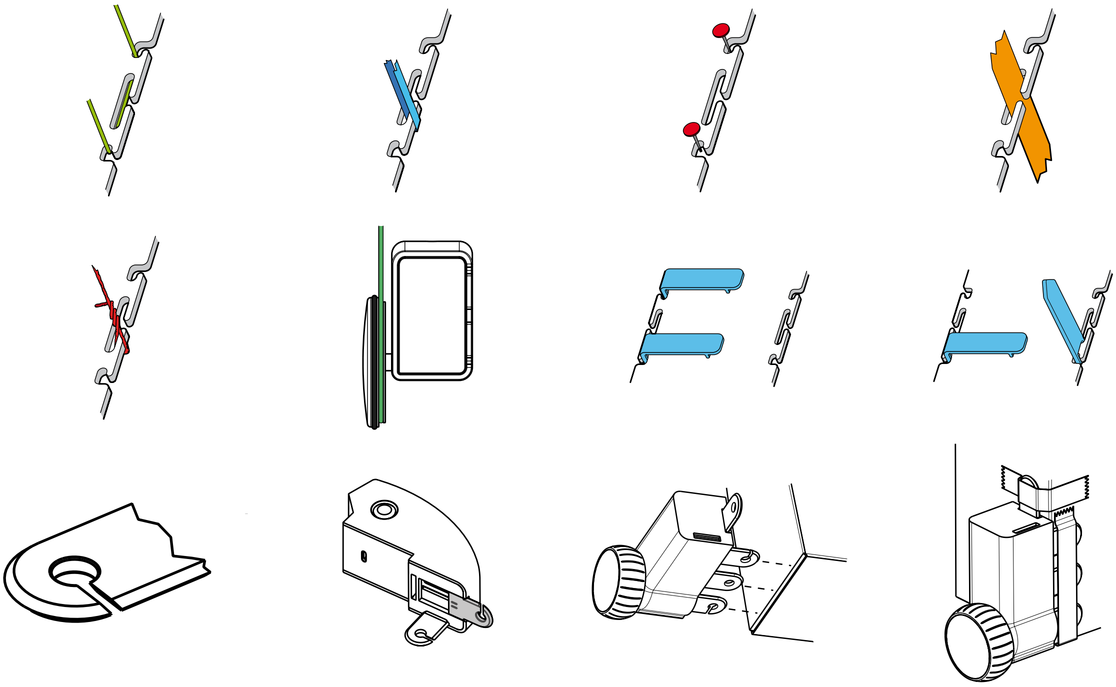


Figure 3.5 – The designers imagined several ways to attach modules to the robotised object (design by Julien Ayer & Luc Bergeron).

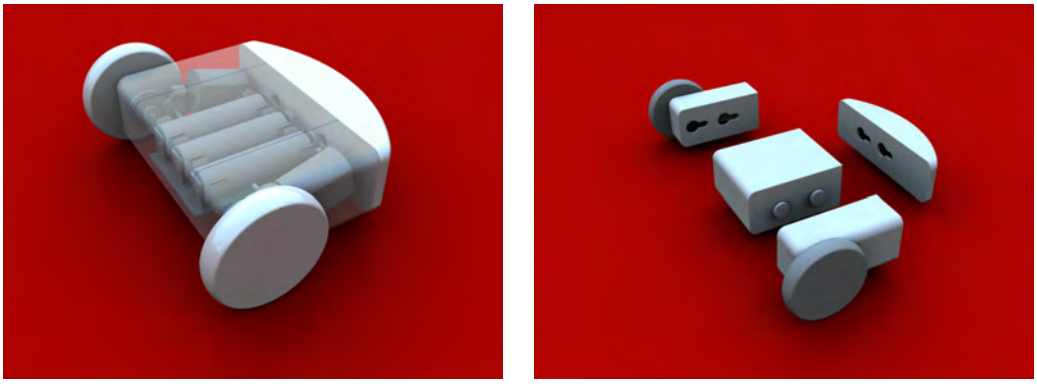


Figure 3.6 – Finally, the first Thymio became a robot that could be broken down into smaller modules (concept images by Michele Leidi).

Figure 3.7 – The validated design of Thymio. Some details were modified when setting up the production (rendering by Julien Ayer).

3.2 The first Thymio

3.2.1 Concept

Starting with the same concept - having two wheel modules, one sensor module, one central battery module and a simple button interface- Thymio became a bit more elaborate than Robokit. The behaviour was changed from simple line following to obstacle avoidance (easier to use on any surface). Therefore the three downwards pointing IR sensors were replaced by five horizontal ones. In addition, the electronics needed a plastic case for protection, if the robot was to be distributed to people. Several shapes and looks developed by Luc Bergeron and Julien Ayer of écal were considered (see Fig. 3.4). The discussions during this development phase focused on the attachment means the robot would offer for the construction (see Fig. 3.5). Gradually, the shape of the kit changed to look more like a finished, complete robot that could be broken down to four modules (see Fig. 3.6).

The final design of Thymio was white and simple, like a blank page, a basis on which something could be built or drawn (see Fig. 3.7 and Fig. 3.8). The cables could not be removed to avoid confusion; instead, they folded into the robot when assembled. The designed attachment means allowed for different assembly techniques (see Fig. 3.9). It was decided to make the inner plastic parts transparent, giving the possibility to observe the inside. This was to avoid the "black box" approach; even though not all the low-level details of the robot's functioning were explained, it left an open door for curiosity. The robot had three different behaviours that were presented as different "moods" for the robot. The *friendly* one follows any object ahead of it, the *curious* one just roams around avoiding obstacles, and the *scared* one stays still until something passes in front of it, in which case it goes away. The different behaviours were emphasised with sounds and lights: green and red LEDs allowed to produce three different colours. Green for the friendly behaviour, red for the scared, and yellow (mix of green and red light) for the explorer. A single button allowed to change the behaviour or turn the robot on and off.

Figure 3.8 – The produced version of Thymio. Some details were modified when setting up the production: the front plastic part was changed to translucent white to show the LEDs and holes were added for the IR sensors. The attachments changed slightly.

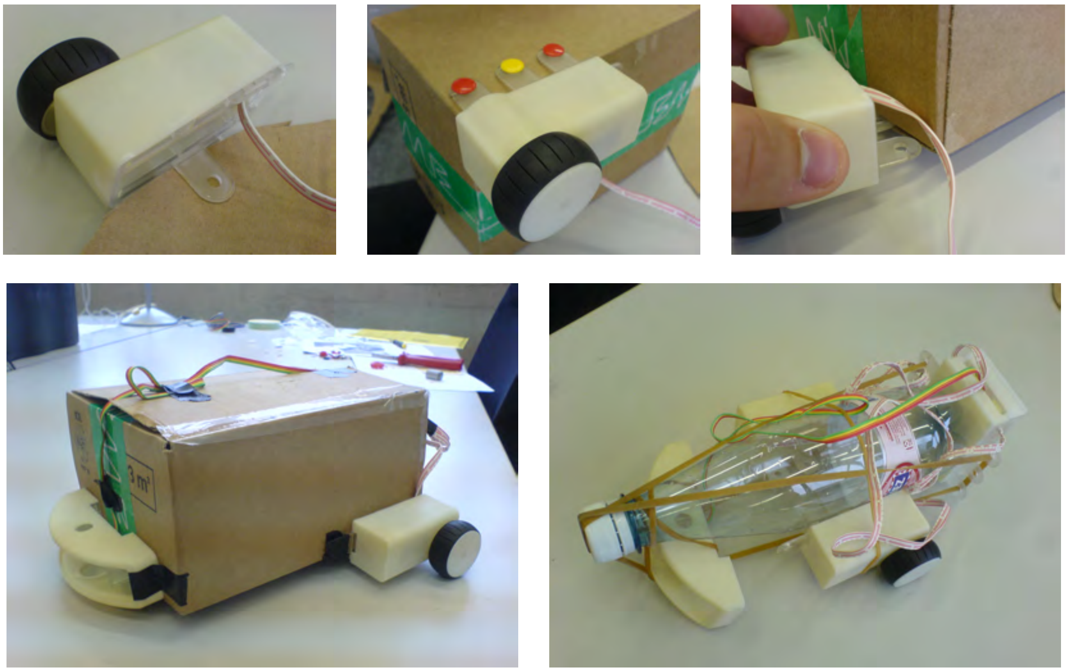


Figure 3.9 – The modules can be attached in different ways to the support (photographs by Michele Leidi).

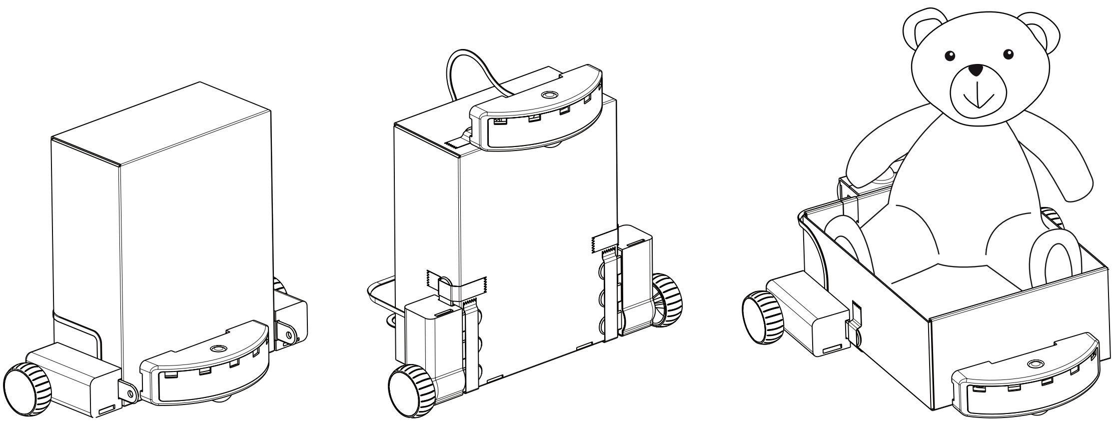


Figure 3.10 – The box used in the packaging can serve as a support for the first construction (examples given in the instruction leaflet).

We hoped users of Thymio would use it to “robotise” their objects by fixing it around them, build new robots in handicrafts, reuse the kit for different object using the different moods. The name Thymio itself came from the greek ϑύμος, which expresses the part of the spirit that animates living beings, the emotions. Thymio allowed to give this ϑύμος to any object.

The box’s design also underlined this “blank page” philosophy. Its size and holes corresponded to the shape of the robot’s modules, thus becoming an ideal support for the first construction (see Fig. 3.10). To keep the box white, as another support for drawing, all information was printed on a removable jacket. We ordered 1’000 units of these kits.

3.2.2 Experience in outreach events and feedback from the public

During the 2009 Robotics Festival, the first Thymios arrived into the hands of children. Workshops of 1 hour took place 6 times a day, welcoming 50 children aged 6 to 12 at a time. They started by a short introduction to robotics, then the children could discover their robots and start building with crafts materials under the supervision of assistants (one adult for two children). They could take their robots home at the end against a fee of CHF 49. The workshops received huge success and took place again at the 2010 Festival. However, for this new edition, the format of the workshops was revisited. Indeed in 2009 the format was a bit rushed; children did not get enough support and had not sufficient time to test their robots once built. 50 participants in a single room felt too crowded and the assistants rushed the kids to all build the same example robot, to be sure that they could welcome the next group (see Fig. 3.11).

In 2010, we welcomed in total as many children as in 2009, but the workshop sessions were longer (1h30) with fewer children (15 at a time). Three variations of the Thymio workshop were held at a time in different rooms. While all workshops were still based on handicrafts and offered to the same age range, we tried to give the three versions various focuses to appeal to different groups of children:

- *Animals* In this workshop the children concentrated on decoration, making the robot look like an animal with different crafts materials like colour paper, feathers, wool, eyes... This was the most creative workshop, where the assistants encouraged the children to build something personal. After the constructions children played with each other and their robots in a common area.
- *Challenge* The children could first test their robots; they were presented with a special obstacle course made of slopes, different textures, holes, and discovered that the basic Thymio could not pass these obstacles as is. They had then to think about ways to customise it so that it would become more "all terrain", and could build wheels, change the general shape and size of the robot to attain their goal. They could at any time go to the obstacle course and test their solution.
- *Cardboard constructions*: here the goal was to learn a special technique of building with cardboard, using its flexibility or rigidity depending on the desired result. The robot served as a support or a motor to animate the construction. Two primary school crafts teachers animated this workshop, Jean-Maurice Mayencourt and Antoine Regamey.

These workshops attracted 341 children from 5 to 15 years old.

Other events with Thymio robots included TunBasel[3], where people could just stop by and play with a robot or build something, or class visits.

After these experiences, we started to notice that once the children got home, the robot was not used at all anymore. It seemed that our idea to let people robotise any object, take it apart, build something else again and again with our kit did not happen. Instead, people who told us about their use of the robot said that they put it on a shelf, that it had stopped working because of empty batteries and they did not change them.

In addition, we were a bit disappointed to see that most constructions looked the same: using the robot's box because it was convenient and then decorated, or even just the robot itself as out of the box with just some decoration (see Fig. 3.11). People told us that the cables were not very convenient, and we realised that in order to have the expected behaviour, all the modules had to be placed in the correct configuration, like in the basic version: wheels not too far apart, sensors not too high up and horizontal. They also said that it was hard to replace the batteries without breaking the construction after a workshop because the central module needs to be unscrewed, and they had generally grown attached to their creations. Many participants asked if the robot could be programmed and how, or if they could change the basic behaviours or add some. The robot impressed a lot people the first time they saw it, and most of them were very happy with the workshops, but we felt we had missed our goal because it had become a single-use robot. Finally, the quality of the production failed to satisfy us; the parts did not fit well together, the robot was creaky, it did not give the clean impression we were aiming for.

[3] http://www.tunbasel.ch

Figure 3.11 – The most common constructions with Thymio used the box in the configuration shown, or the robot decorated as is (photographs by Silvan Widmer & Frédéric Rochat).

Based on those first impressions, we decided to investigate a bit the use that people made of Thymio, and collaborated with Nathalie Nyffeler of the HEIG-VD who often worked with Luc Bergeron of écal. She taught market studies and gave her class an assignment to investigate what happened to Thymio at people's houses. This has been reported also in [RRB+11].

3.3 Market Study with HEIG-VD

For the second version, we already had some ideas coming from our experience and from the user's informal feedback during the Festivals or class visits. Mrs Nyffeler had an additional meeting with a middle school maths, physics and computer science teacher, Basile Gass, to complete this list of suggestions (see Appendix A for the minutes of the discussion). We then together with écal's Luc Bergeron and Laurent Soldini decided on a list of tentative features that would be submitted to evaluation. The study aimed to understand the motivations and obstacles to Thymio's use at home and to identify the best scenario for the development of Thymio II, by validating the proposed new features with the users (see Appendix B for the complete mandate). The market study was an assignment given to students of HEIG-VD, supervised by Nathalie Nyffeler and Andrea Suriano. Three different tools were used: first, a quantitative survey was sent to all parents who had bought Thymio for their child during the Festival (people could subscribe to the Festival mailing list when registering for workshops); second, qualitative interviews with 8 parents were conducted, and finally a focus group was organised in a primary school class. In addition, the students also interrogated experts and analysed the market for competitors.

We had the e-mail addresses of 362 parents; we contacted some for the interviews and sent the online questionnaire to all the others. Out of 346 people who received the survey, 65 answered.

Among those answers, the feedback is very positive: the parents are very satisfied with both the quality and the price of the workshop (see Fig. 3.12). 96.9% agree that the workshop is of good quality, and 95.4% that their child was satisfied with the activity. 95.3% consider the workshop cheap. To the question "Do you intend to return to the Festival in 2011?" 63.9% answered yes, 29.5% answered maybe and only 6.6% said no.

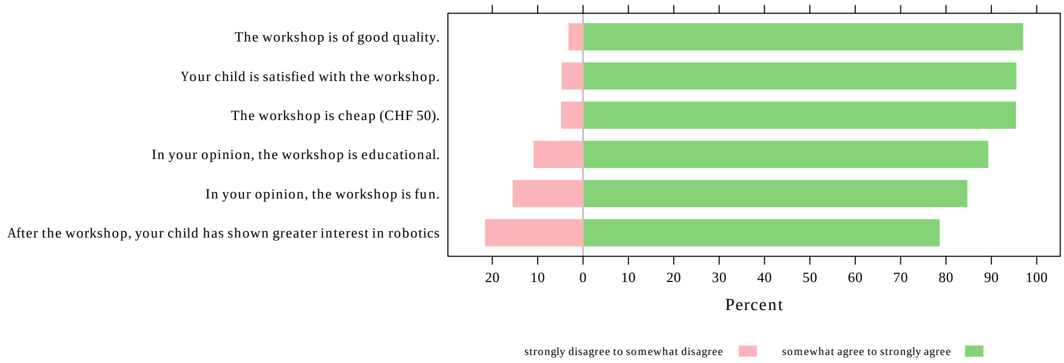


Figure 3.12 – Feedback from the parents of workshop participants in 2010 (n=65, data published in [RRB+11]).

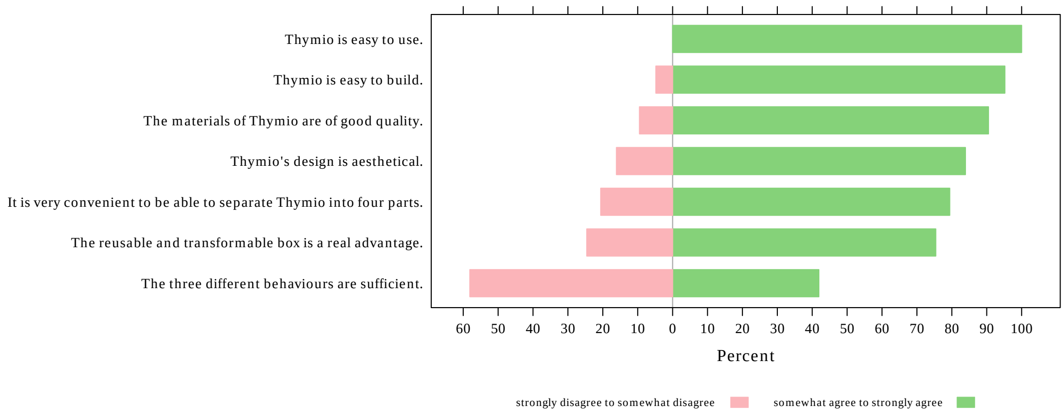


Figure 3.13 – Evaluation of Thymio's characteristics by the parents of participants to the workshops (n=65). The modularity and the usable cardboard box are not as successful as the other characteristics, but what stands out clearly is that the 3 behaviours are not satisfying (data published in [RRB+11]).

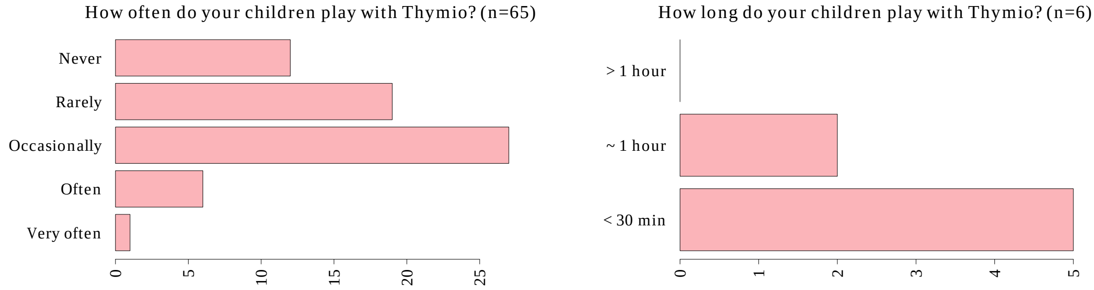


Figure 3.14 – It seemed most children did not use their robots much once at home (data published in [RRB+11]).

From this feedback we could also confirm some of our hypotheses:

- As hinted by the demands during the workshops, the 3 behaviours are not sufficient, 58.1% of the respondents would like to have more (see Fig. 3.13).
- As we had guessed, the robot's modularity and the usage of the box are among the least popular features (see Fig. 3.13).
- Children indeed do not play much with the Thymio at home. Only 10.7% say that their child plays often or very often with it. Among those, most play less than 30 minutes (see Fig. 3.14).

We also asked them to pick the features they would like to have on a new version (see Fig. 3.15). The most popular features were the compatibility with Lego bricks (75.4%), the rechargeable battery (66.2%), the possibility to program the robot (66.2%), a camera (52.3%) and the possibility to record one's voice (50.8%). It is interesting to note that a humanoid or animal shape did not appeal to the respondents. The importance of a rechargeable battery came from a technical issue: the robot consumed energy even while off, so when it was left for several days the batteries needed to be changed before the child could play again. This waste of disposable batteries was a serious drawback for the parents and for us. And because the robot was decorated, the exchange of batteries often required the destruction of part of the decoration, discouraging the children to change the batteries.

The Lego compatibility was tested in the focus group organised in a class of 14 seven-year-old children. The class could use modified robots that had Lego plugs added on top of them (see Fig. 3.16) and lots of Lego bricks to play with. As a result, the kids were immediately comfortable with building the robot. We noticed that with the Lego, they could easily assemble something, then destroy it to build something else. They did not have the same scruple as with destroying something they built out of cardboard and paper.

During the interviews with parents, some more explanations came up. They explained that during the workshop, the three behaviours were sufficient, because there were other robots

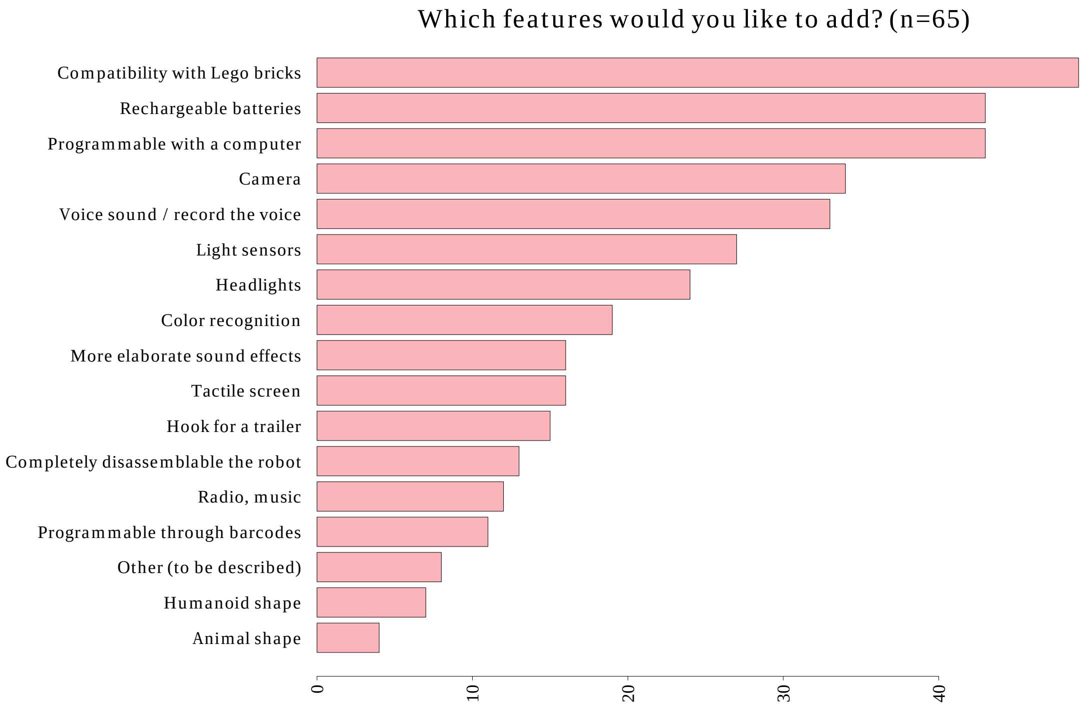


Figure 3.15 – People would like compatibility with the Lego system and reprogrammability of the robot. They also care about the waste of batteries. Other attractive features would be a camera or the possibility to record one's voice. It is interesting to note that a humanoid or animal shape -very frequent in robot toys- is not appealing to them (data published in [RRB+11]).

Figure 3.16 – Children could test a modified version of Thymio: non modular, but compatible with Lego (photos by Nathalie Nyffeler).

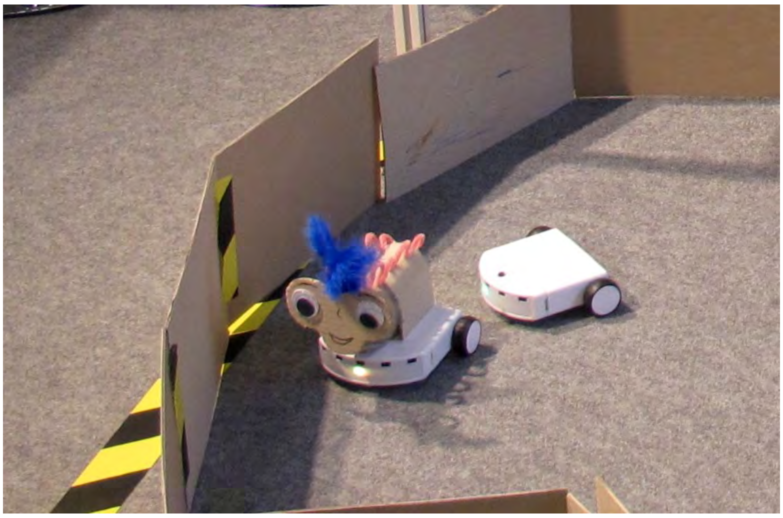


Figure 3.17 – If one Thymio is in explorer mode, an another one (or several others) is in friendly mode, they will naturally form a train. Children generally came up with this by themselves (photograph by Silvan Widmer).

to interact with. For example, children always found that a train could be created by putting one Thymio in obstacle avoidance mode and several others behind it in follower mode (see Fig. 3.17). Once at home, these behaviours seemed too limited. There was nothing more to discover, so the children kept their robot on a shelf, more like a decoration.

However, it was stated by several parents that children get really attached to their Thymio and are for example reluctant to let someone else use it. This attachment probably came from the workshop during which the participants played with and customised their robots. Contrasting with this, experts or people who did not know Thymio found it too simple or cold in its design.

Finally, we could validate that the sales price should stay below CHF 100.

3.4 Influence of the e-puck

We will briefly describe the e-puck robot (see Fig. 3.18), as it has many common points with Thymio II and influenced greatly its design choices. Just as Thymio II was developed mainly for the education of children, the e-puck is such a platform for students in engineering [MBR+09]. Different laboratories of EPFL collaborated to come up with specifications for this educational robot. Students could test the first prototypes in the academic year 2004-2005. The final version of the e-puck, with corrections based on the tests and some optimisation for production, came out during the summer 2005.

Sold at around CHF 800, this 7.5 cm cylindrical robot fits comfortably on a desktop and possesses a wide range of sensors, actuators, and interfaces one can find in several engineering sub-domains. Its dsPic microcontroller allows for signal processing and can be programmed

Figure 3.18 – The e-puck robot.

in C or Assembly. The robot features eight IR sensors, a three-axis accelerometer, three microphones, a colour camera, two stepper motors, a loudspeaker and several LEDs. In addition, it offers the possibility to add extensions easily to widen its capacities. Since its introduction, the e-puck was regularly used in EPFL bachelor and master courses, in research and sold throughout the world.

The important requirements in its development were a low price (for university standards), desktop size, wide range of sensors and actuators, user-friendliness and open design. All those criteria were retained in the development to Thymio II, the only difference being the target audience. Indeed, "cheap" for a university is different from "cheap" for a child.

While not intended for children, the e-puck was also used for their education. During the 2010 Festival, programming workshops on simulated e-pucks were held [MNM08]. This gave us hints at the fact that children managed to program robots with many sensors and comforted us in the direction we were about to take.

3.5 Concept and Philosophy of Thymio II

Based on the HEIG-VD study, we defined the new concept for Thymio II, still in a close collaboration with écal (Luc Bergeron and Laurent Soldini). Several conclusions were drawn form this study and from our previous experience:

- The general shape and size and the white look of the robot were appreciated by the public, but the modularity, while impressive at first sight, did not actually allow for many configurations, lowered the quality of the robot, and raised the production costs.

- Lego plugs would be appreciated by the owners of Thymio, and were immediately recognised by the children. Other attachment means in several places could let the users build something out of crafts materials also. This could bring back the flexibility of use lost by the abandonment of the modularity.

- The pre-programmed behaviours were appreciated, but not sufficient. They should be made more varied and complex.
- The public wanted programmability. However, with only the five sensors of Thymio, we had already found it difficult to come up with three interesting behaviours. And from the e-puck experience, we knew that more sensors made the programming experience richer, thus more sensors were needed.
- We realised that feedback (light or sound) helped the users understand. We decided to place LEDs all over the new robot to highlight its functioning.
- The parents demanded the robot to be rechargeable, because changing the batteries was inconvenient and the waste disturbed them.
- An open hardware and software design facilitated the transition to the production phase, as seen in the case of the e-puck.
- There was a demand for affordable robots.

The production cost was a primordial point during the development phase. As we knew there was a psychological barrier for the sales price at CHF 100, and teachers with whom we had talked also mentioned the price as a major drawback when they wanted to bring robots into schools (for example, a Lego Mindstorms set cost around CHF 450 at the time), we did our best to keep all costs low. Thus, some expensive options like an RF or Bluetooth connection and the camera were dropped.

Finally, to maintain the idea of giving access to knowledge to everyone, and to keep the same philosophy as in our software Aseba which was open-source, we chose to make Thymio II completely open hardware like the e-puck. In addition, many projects that were open source had managed to build a strong community (like Arduino and Raspberry Pi), which could prove extremely profitable to generate materials and improve the contents.

3.5.1 Specifications for the development of Thymio II

When developing Thymio II, all of our conclusions, along with observations of the state of the art and new ideas, allowed us to come up with a requirements list that would guide our design. The final specifications were given:

- Affordable robot, ideally a sales price lower than CHF 100
- Total production cost around CHF 35, including around CHF 20 for the electronics (ten francs more than the first Thymio, mainly to improve the electronics)
- Same general shape, size and colour as Thymio, but in one block
- Functional out of the box, with similar behaviours to Thymio, plus new ones

- Programmable
- A wide choice of sensors and actuators
- LEDs to highlight the sensors' activity
- Compatible with the Lego system, and allowing construction with crafts materials
- Open-source
- Open-hardware
- Designed for series of at least 1'000 units
- Safe and robust for children (fitting the CE toy standards)
- Rechargeable through a micro USB connector, to keep compatibility with the new cellphone standards
- Accessible to young children and interesting for teenagers at the same time
- Appealing to both genders
- With a website to promote the community and exchange of information
- Adequate to teach notions of robotics, programming, and introducing technology

In the next chapter we will describe the design of Thymio II, resulting from this requirements list. We will detail both its hardware and its software.

4 Design of Thymio II

This chapter presents all the characteristics of Thymio II's design. We saw in the previous chapter the list of requirements we had during the development of Thymio II. Starting from it and in close collaboration with Luc Bergeron and Laurent Soldini, we kept in mind the production aspects. The results is Thymio II, a small, white, wheeled mobile robot that has many sensors, a few pre-programmed behaviours, and can be programmed through Aseba Studio. In this chapter we'll explain the mechanical, electronic and software aspects of Thymio II. Several people contributed to this development: the author of this thesis led the project with the help of Professor Francesco Mondada, coordinated the efforts, took the main design decision, such as feature and components selection, as well as supervised production-related aspects. In addition, she took part in the mechanical and electronic design of the robot. Luc Bergeron and Laurent Soldini designed the look and shape of the robot, as well as the buttons interface, and took part in the concept development. Dr Michaël Bonani worked on the mechanical design, electronic design, and did the routing of the PCB. Philippe Rétornaz was the lead developer of the firmware and took part in the electronic design. Dr Stéphane Magnenat is the lead developer of the Aseba framework and provided his advice in adapting it to Thymio II. Josep Soldevila developed the first version of the inter-robot communication under the supervision or Philippe Rétornaz and the author of this thesis.

4.1 Overview

The produced version of Thymio II is presented in Fig. 4.1. The design was developed within academic projects, and then the production and commercialisation were taken care of by the nonprofit association Mobsya[1]. Users can buy one robot in a box with a micro USB cable and a short information leaflet. The robot has pre-programmed behaviours, which will be described in Section 5.1.2. In order to program it, users can visit the website, www.thymio.org, and download the free software, Aseba Studio (see Section 5.2 and Section 5.3). The website

[1] http://www.mobsya.org

Figure 4.1 – The Thymio II robot is a small wheeled robot for children (image courtesy of Association Mobsya).

contains all design information, as well as documentation, examples, and a forum. It was created in the form of a wiki so that anyone could contribute.

The robot itself was designed specifically for production, so once the concept had been sketched out we proceeded by following a few design rules:

- limit the number of plastic parts, to avoid bad assembly because of tolerances in the plastic moulds like on the first Thymio
- make the assembly straightforward
- choose electronic components to ensure programming possibilities but keeping within the budget
- aim for CE toy certification

In the next sections we will describe first the mechanical aspects of the design, then the electronics, and then the firmware.

4.2 Hardware

4.2.1 Mechanical Design

As said previously, our goal was to keep the general shape and look of Thymio, while dropping the modularity, diminishing the number of parts and simplifying greatly the injection moulds.

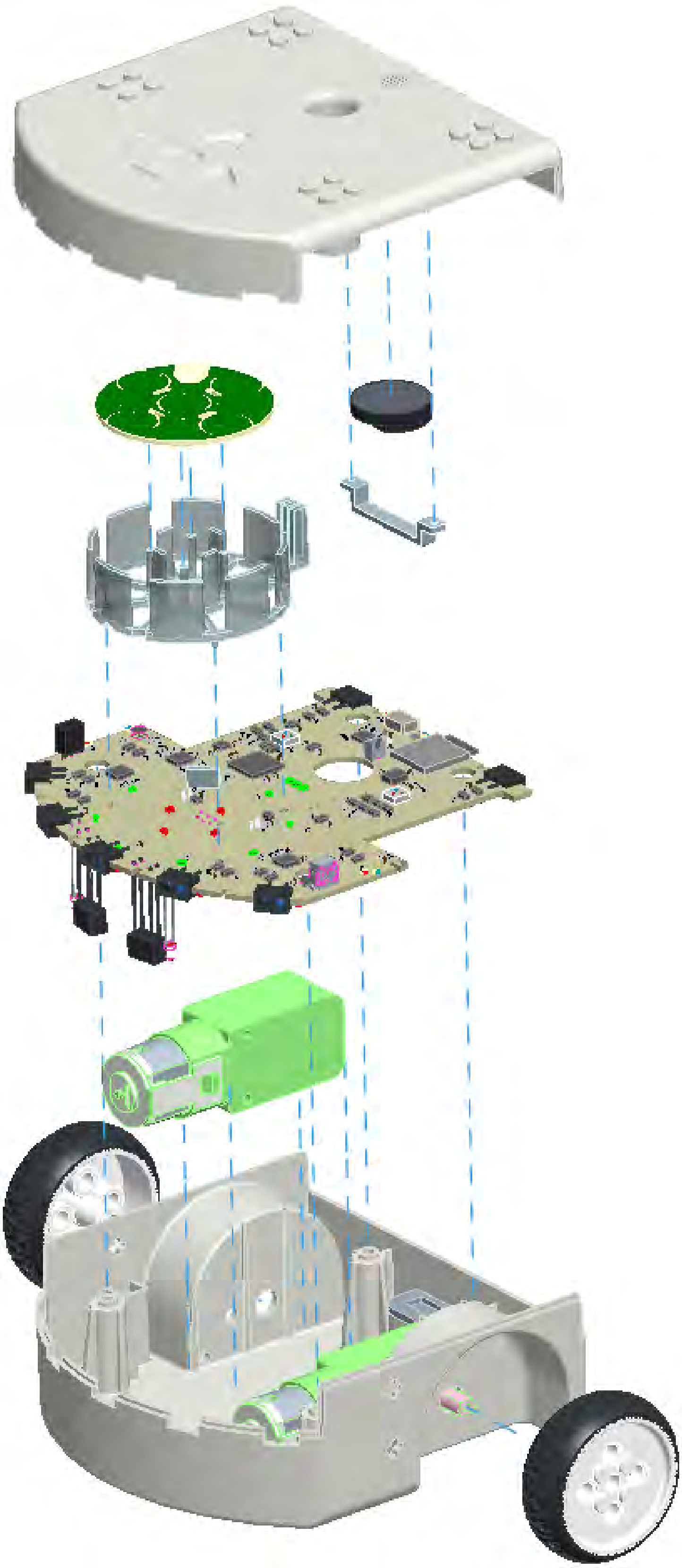


Figure 4.2 – Exploded view of Thymio II (image by Norbert Crot).

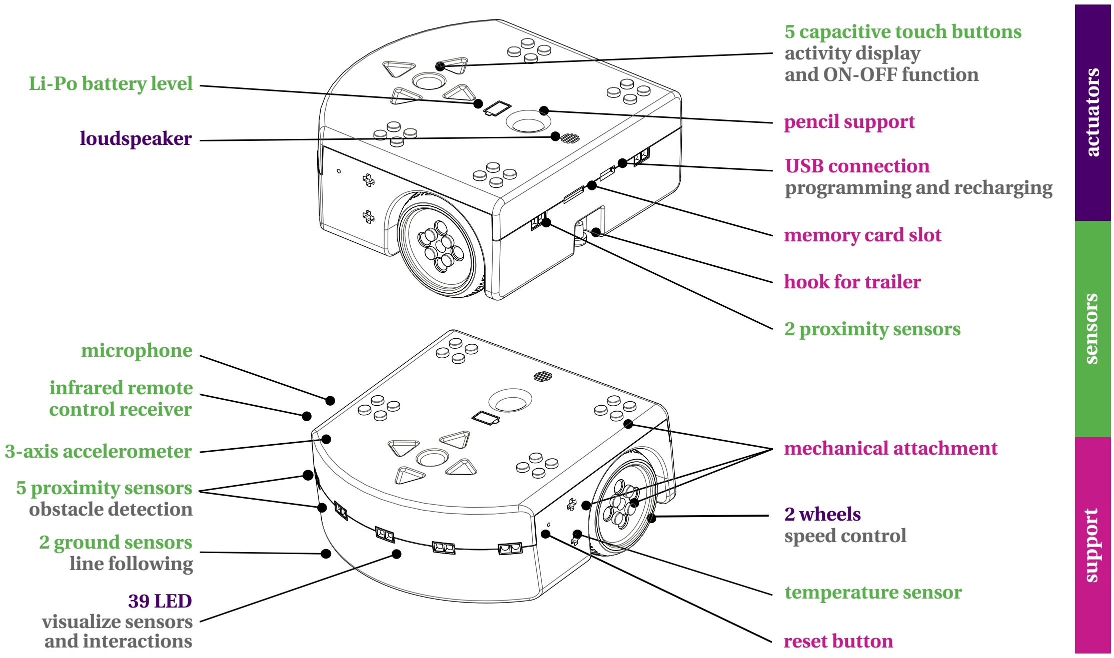


Figure 4.3 – Overview of all Thymio II's features (courtesy of http://www.thymio.org).

In order to facilitate the mounting, we decided to have a plastic shell in two parts, with the PCB carrying all components sandwiched in between (see Fig. 4.2). Plastic injection remained a preferable method for mass-production of cheap robots. On the first Thymio, if the robot fell, the axes of the wheels would get bent because they were too fragile. Therefore, Thymio II's wheels were moved to be more enclosed inside the robot, in order to protect them. This configuration also allows to lay the robot on its side without any friction and use it not as a moving device, but for example to animate a construction. This widens the scope of the possible uses for the robot. The dimensions of the new robot were similar to the first Thymio's: around 11 by 11 by 5 cm. Thymio II would have five buttons on top instead of one, and we opted for capacitive touch buttons to ensure robustness and avoid holes in the plastic case.

We chose a semi-translucent white ABS as the material: thus all LEDs placed next to the case can be seen through the plastic, with a bit of diffusion (see Fig. 4.4). The RGB LEDs are powerful enough to be seen through the plastic, even though they are placed a bit further from the plastic case. For the top LEDs, as the were too far from the plastic cover, and because we wanted to obtain more defined shapes with the light (see Fig. 4.5a), we added polycarbonate waveguides (see Fig. 4.5b). This part also serves as a support for the touch button PCB, which should remain as close as possible to the case (see Fig. 4.5c). The plastic was made thinner in places where the waveguide was fixed and on the touch buttons. This configuration made the assembly more difficult because the cable linking the two PCBs had to be soldered with the waveguide already in place.

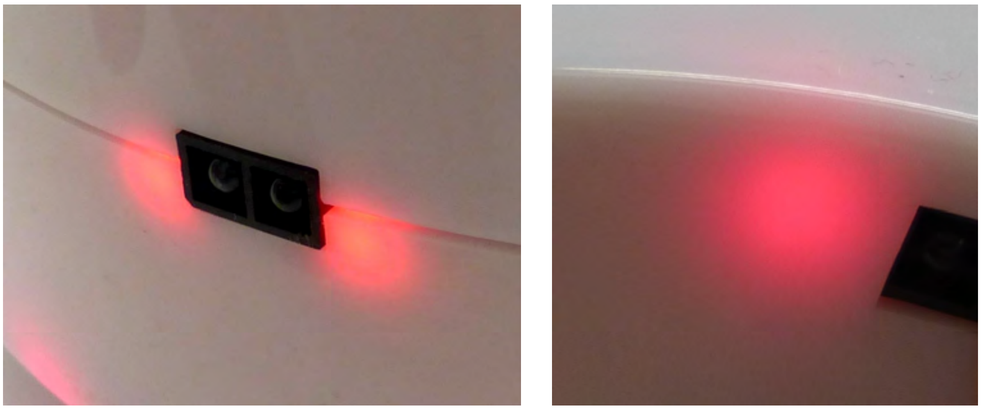
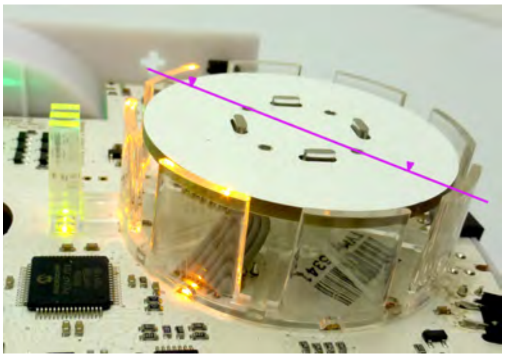
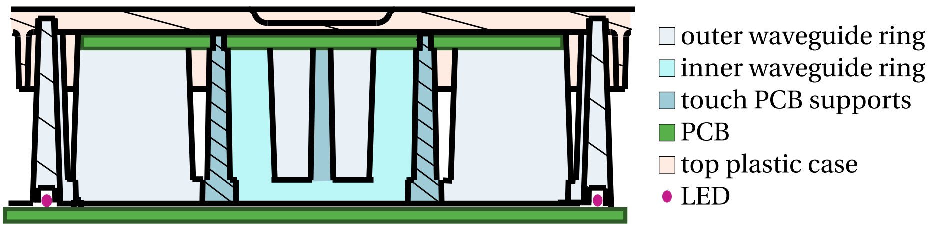


Figure 4.4 – The semi translucent plastic diffuses the light of the LEDs while giving a clean white look to the robot.

(a) LED diffusion delimited with a waveguide. These LEDs are placed 16 mm away from the plastic cover.



(b) The waveguide for 15 LEDs is made as a single plastic part, which also serves as a support for the capacitive PCB. There are four LEDs in the inner ring, eight in the outer ring, and three in the external part. The line on the picture indicates the section shown below.



(c) Sectional view of the waveguide. We see the capacitive PCB is held tightly against the plastic cover by the guide's supports. In the middle, we can observe the hollow outline of the central button: the plastic is made as thin as possible to let the finger come closer to the PCB. The waveguide's columns lead the light from the LEDs on the main PCB up to the plastic cover, also made thinner in places to define the shape of the light.

Figure 4.5 – With the waveguides, distant LEDs can have a more defined shape. In addition, it maintains the capacitive touch PCB close to the plastic case.

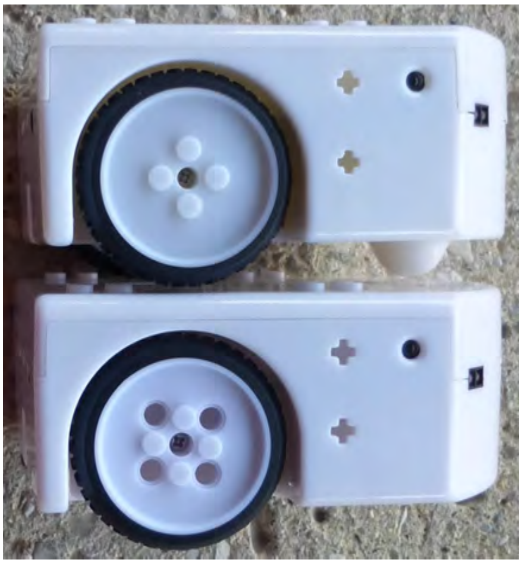


Figure 4.6 – The new wheel (down) has additional Lego technics holes to facilitate the transmission of rotation.

As mechanical fixations to build things on and around the robot, we put four basic Lego plugs on top, two Lego technics crosses on each side, and basic Lego plugs on the wheels (see Fig. 4.3). We later added Lego technics holes on the wheels to better withstand torsion when transmitting rotation (see Fig. 4.6). A hook on the back (also Lego-dimensioned) allows to attach a trailer. A hole at the rotation centre of the robot lets the user place a pen to make drawings with the robot's movements.

In addition, we had to take care not to leave holes in the case that would give the possibility to insert pins or needles and risk a short-circuit, to ensure getting the CE certification. All the holes had precise functions: for all IR sensors, one small hole for the reset button, Lego technics fixations, micro SD card slot and micro USB slot. Different covers were placed to protect holes that gave access to the PCB (see Fig. 4.7).

We chose motors from TTS which contain a simple DC motor with a reversible gear. Reversibility is essential to prevent damage if the robot will be manipulated by children. The motors are held against three flat surfaces and secured by a screw (see Fig. 4.8c). The wheel is screwed directly onto the output of the motor-gear block.

The battery is placed between the 2 motors, underneath the PCB, and thus completely isolated from the user. The two parts of the plastic case are held together by four screws (see Fig. 4.8). This robust design for the robot allows for it to fall from the table top without being damaged, while possibility to open it for repairs remains.

(a) The cross-shaped holes gave access to the PCB. Thus, walls were added on the plastic case.

(b) Because of the shape of the mould, the trailer hook left an access to the PCB. A cover was glued on top of the hole.

Figure 4.7 – The PCB should not be accessible by a pin or needle to fit the CE certification. Therefore, walls were added on possible entry points.

4.2.2 Electronics

The main criteria when choosing components for Thymio II was generally their cost. We wanted to have as many sensors as possible, while keeping the total cost of the electronics in a robot at approximately CHF 20. The second main constraint was the very short time available for the development; after the main concept was defined in october 2010, the goal consisted in having the first batch of Thymio II ready for the 2011 Robotics Festival in May.

The overview of Thymio II's electronics is given in Fig. 4.9 and the complete schematics and PCB characteristics can be found on the Thymio II wiki[2] under a Creative Commons Attribution-ShareAlike 3.0 Unported License. Thymio II has two PCBs, the main one carrying all the components, routed in two layers, is maintained in the middle of the robot by the two halves of the plastic hull. The second one, for the capacitive touch buttons, is held tightly against the top of the plastic case by the waveguide; an air gap should be avoided.

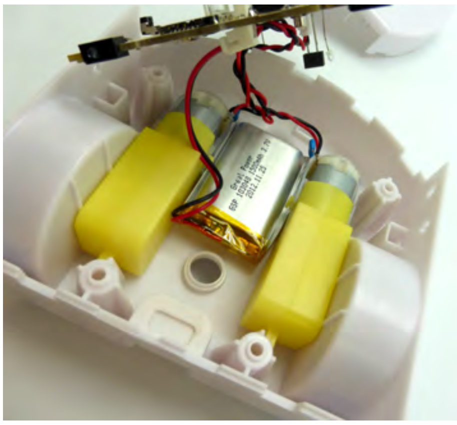
Hereafter we will briefly describe the most important choices we made for the components.

Microcontroller

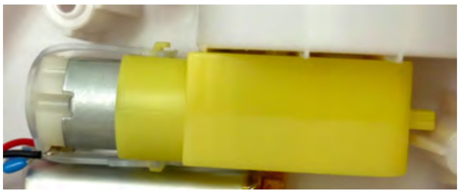
This choice was heavily influenced by our previous experience in the laboratory. We had little time to develop the robot, thus we opted for a Microchip microcontroller, though a bit expensive in our budget, because it was well known to our group. Among others the e-puck and MarXbot modules [BLM+10] also used Microchip microcontrollers. This meant that the firmware development would be much faster thanks to the expertise we had acquired.

[2] http://www.thymio.org/thymiohardwaresource

(a) Bottom of Thymio II. One can see the two ground IR sensors, the slider ball, the four screw holes, the pencil support hole and the trailer hook.



(b) Inside the lower case, motors are screwed in place and the battery is placed between the two.



(c) Detail of the motors fixation.

(d) The waveguide, touch PCB and main PCB are assembled separately. The motors and battery are connected to the PCB which is placed on top, all IR sensors fitting in the spaces provided. Finally the top case is screwed in place, after plugging the loudspeaker.

Figure 4.8 – The Thymio II is mounted from bottom to top.

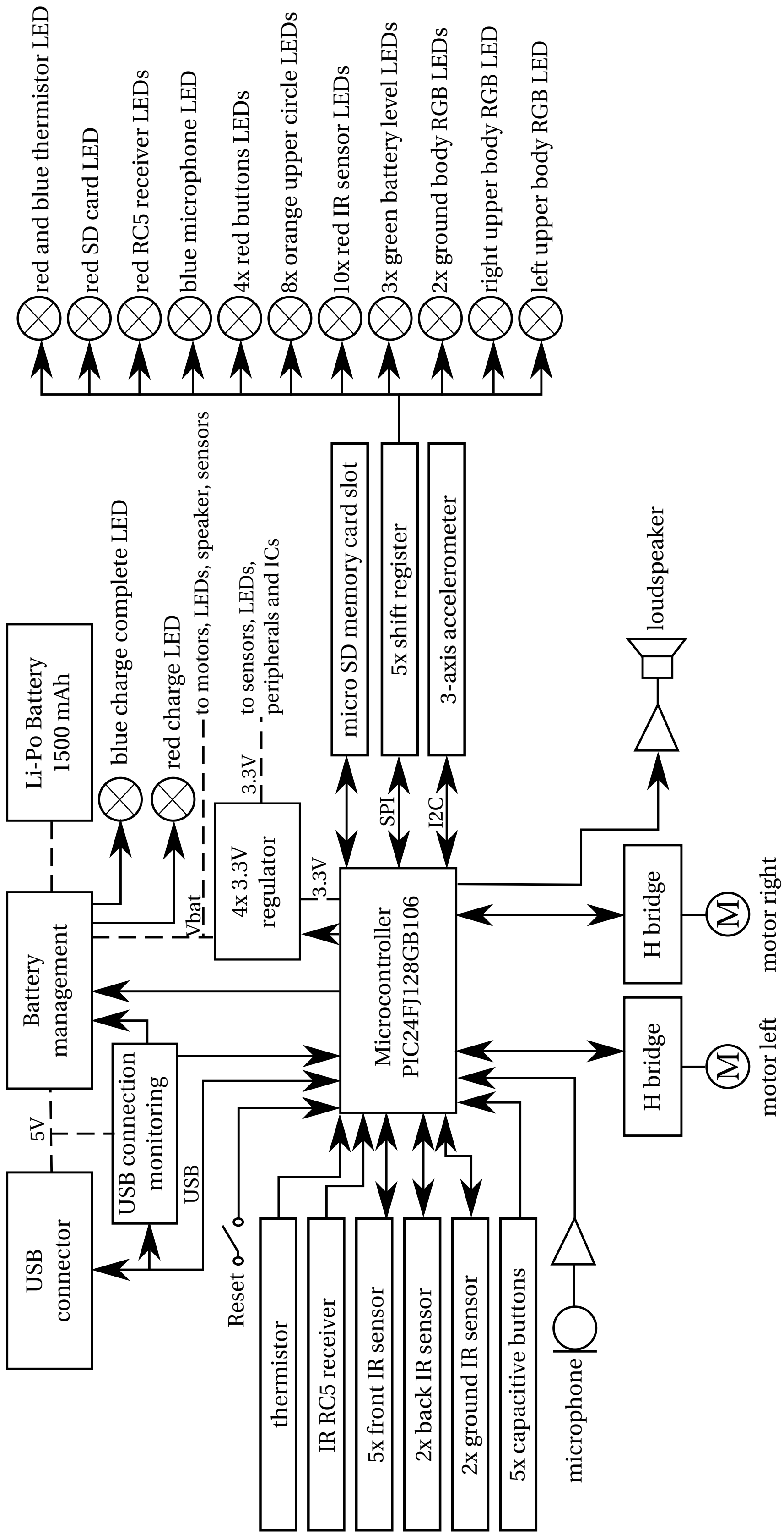


Figure 4.9 – Overview of the electronics of Thymio II.

After a brief review of different possibilities, we opted for a PIC24FJ128GB106. Cheaper than a dsPIC, it also had the advantage of having the capacity to act as USB On-The-Go (OTG) host or device and supporting capacitive touch applications. We selected the 128 kB flash option to ensure that users would be able to store their custom program on the robot in addition to the basic ones. We exploited the microcontroller to the maximum; no pins were left available. However, possibilities of extensions exist thanks to the I2C bus (a connector footprint was placed on the PCB to give the possibility of an addition), or through the micro SD card connector

Proximity sensors

All basic and well known behaviours like obstacle avoidance, line following, object following or stopping at the edge of the table, required proximity sensors. We picked low-cost IR sensors from Everlight, consisting of an IR LED and an IR phototransistor: the ITR9909 (USD 0.16). With five sensors placed horizontally on the rounded part in front and two on the back, Thymio II can see obstacles ahead and orient itself to avoid them, and detect a presence behind (mounted on the edges of the PCB). Two sensors in front of the sliding ball point to the ground (mounted perpendicular to the PCB) and can either detect holes (for example the edge of the desk) or differentiate levels of grey on a flat surface.

The implementation differs between the horizontal sensors and the ground ones, because of the limited number of Analog Digital (AD) converters on the microcontroller. The ground sensors use the AD converters; two measures are taken on the phototransistor, once with the IR LED emitting light (20 mA pulse) and once in ambient conditions. The difference of the two reflects the distance to the object in front.

The electronics on the horizontal sensors, inspired by the one found on the Wanda robot[KSLW10], works in the following way. A short and intense pulse of IR light is emitted (100 mA). The phototransistor will drive a current that depends on the amount of light reflected, discharging a capacitor. As soon as the light pulse is over, the capacitor takes a certain time to recharge. At the end of the filter, a pulse is generated, the duration of which depends on the amount of light that was reflected, and thus on the distance to the object in front. This duration is measured precisely by the Input Capture module. With this method, only a very short pulse of light is needed; therefore we can afford to pulse all front sensors at the same time with quite a high intensity to see farther. In addition, the filter is high-pass, avoiding sensitivity to ambient light. Finally, this method allows to easily add communication capabilities to the robots. Very short pulses are emitted at a frequency of 10 Hz; by adding another pulse in the free time in between information is transmitted to another robot. Data is encoded in the time between pulses; this solution was implemented since firmware v7 by Philippe Rétornaz and Josep Soldevila and will be described in more details in Subsection 4.3.3

Accelerometer

With the omnipresence of accelerometers in smartphones nowadays, their prices have dropped drastically. Very quickly, we considered that this would be a great feature for Thymio II. It would allow detecting free-fall, shocks and the robot's orientation in space. At EPFL, in the micro-engineering third year's embedded programming courses, the exercises with the e-puck's accelerometer were quite successful, as they were entertaining (they involved hitting the robot and making it emit screaming sounds, or throwing it in the air to detect free-fall).

We chose the MMA7660FC from Freescale. Capable of detecting ±1.5g, it uses I2C communication, has auto wake/sleep feature for low-power consumption and cost only USD 0.84.

Capacitive buttons

Opting for capacitive touch buttons had the advantage of avoiding mechanical pushbuttons, increasing robustness, and making the injection mould simpler. All five buttons were designed on a single PCB, placed underneath the top plastic case, and held in place by the waveguide.

Power

We picked a rechargeable 3.7V, 1500 mAh LiPo battery with protection; this gives an autonomy of more than one hour to the robot, when using motors and LEDs. Since 2011 the european standard for cellphone chargers has been set to micro USB, so we decided to opt for this connector. This would allow people to use their own chargers for the robot, and USB would serve to communicate with the computer and Aseba Studio.

The MCP73871 from microchip manages the battery; it can charge the battery and power the system simultaneously. In addition, it offers different charge modes (100mA or 500mA) depending on the input power source. It gives charge status and fault conditions indicators and provides an output voltage between 5V (when USB is present) and 2.6V (when the battery cuts for the low voltage; normally the robot should be recharged before reaching this). To detect it the robot is connected to a wall charger or a USB port, and select the charge mode for the MCP73871, we use the FAN3988 from Fairchild semiconductor. It also lets the microcontroller know if USB communication is present.

The main system is powered at 3.3V through several AP7331 Low DropOut (LDO) regulators from Diodes Incorporated. They were chosen for their low price (USD 0.12) and their very small power consumption. One powers the main part of the system and the microcontroller; this one always stays on. Additional ones ensure that enough current can be provided for some LEDs and for the SD card; one is used for all analog signals. Those can be turned off to consume less when the robot is in sleep mode

LEDs

The LEDs used were chosen for their low price and good luminosity, from Kingbright and Everlight. The robot needed many LEDs to fit our philosophy; this means more pins were needed than available on the microcontroller. We used the MC74HC595A to increase easily the number of LEDs. This device can drive eight LEDs at a time and communicates through the SPI protocol, giving the possibility to chain several of them. It can input 20mA per pin, making it capable of driving directly all the red, green and orange LEDs for the sensor visualisation. All those LEDs have forward voltages around 2V and can be powered on the 3.3V. The blue LEDs' forward voltage can reach 3.2V, thus they cannot be powered on a 3.3V source. All blue and RGB LEDs were driven in current on the voltage provided by the battery charger (which can vary greatly).

Motors

Motors are driven through H-bridges and a feedback signal is sent to the microcontroller to sense the induced voltage (back IMF) and thus the motor's speed. A software PID regulator then controls the motors according to the target set by the user.

Other components

From the HEIG study we knew that a good feature would be the ability to record and play sounds. We went for a cheap microphone (USD 0.10) and speaker (USD 0.35). In addition, a micro SD card would allow to record longer sounds, as the robot's memory is too limited. It could also serve to store programs that the robot can load on startup.

People also wished for the capacity to remote control Thymio II, thus we added a 36 kHz IR receiver. As one final pin was available on the microcontroller, we chose a thermistor to sense temperature.

4.2.3 RF module

In the first version of Thymio II, we evaluated the possibility to have a wireless connection with the computer, but the different solutions envisioned (RF, Bluetooth, Zigbee) were all too expensive (the cheapest solution would still cost around USD 10, one half of our budget for electronics).

An RF module is now under development, and described in [RRM+13]. This small PCB can be added inside the Thymio II, on the connector for the I2C bus. The newest version of the software will support this additional module and a USB dongle on the computer side will allow communication.

4.3 Software

For the software, we wanted to keep some pre-programmed behaviours like those of the first Thymio, but we also wanted the possibility to program a custom behaviour. Like this, the robot would be usable directly out of the box, and at the same time leave space for the user's creativity. We decided to use Aseba, a framework developed within the laboratory, for several reasons. Of course this gave us the possibility to customise it to suit our needs, but it also had the advantage of proposing a lightweight virtual machine (VM), adapted to microcontrollers. For the user, working inside this virtual machine has some advantages:

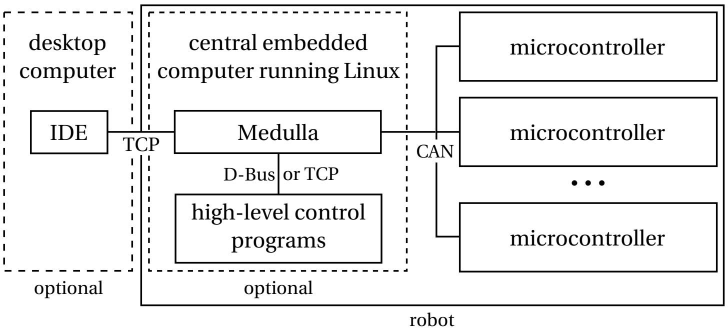
- Programming is safe, because the low-level aspects such as setting inputs and outputs correctly are already taken care of. There is no risk of damaging the robot by entering the wrong command.
- The pre-programmed behaviours can exist in parallel to the virtual machine, therefore when programming the robot the initial program is not lost.
- The user interface is customised to the robot, there are high level functions with explicit names and documentation.

The framework also makes debugging easy and takes an event-oriented approach.

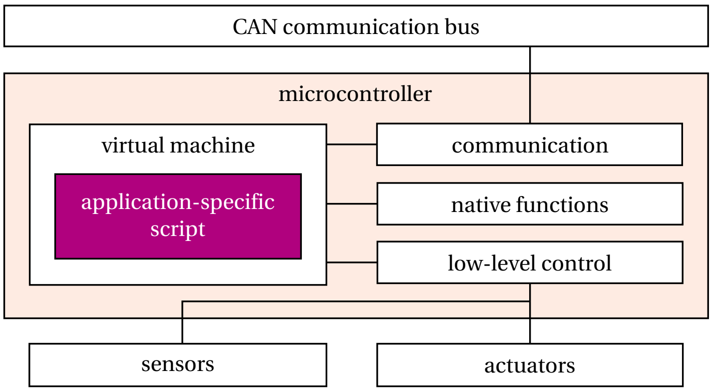
Event-based programming, as opposed to sequential programming, aims at coordinating actions with events to optimise the resources and not do computing when it is not useful. An event is basically something that happens; practically it means that information has been updated, for example a new sensor value was read, or a module has answered a query. It is then possible to do the computations that depend on some value only when it is relevant. Event-based programming is linked to reactivity, and decision making instead of just following blindly a sequence of orders. This fitted particularly well with our wish to introduce notions of technology via the sensor-actuator loop example.

The final firmware has pre-programmed behaviours in parallel with an Aseba Virtual Machine, which takes over when executing user code or when connecting to Aseba Studio on the computer. The firmware itself is written in C and Assembly, open-source and available from the wiki.

When turned on, the robot is in menu mode. Using the arrows, the user can navigate between the different modes and the central button allows to activate them. In this case, the RGB LEDs start pulsating to show that the mode is activated. Whenever the robot is connected to a computer and Aseba Studio is launched, it switches to user mode and the virtual machine takes over. In this mode, the user can write Aseba code which will in turn be executed by the virtual machine. In the next sections we will describe the important parts of the firmware as well as detail the Aseba virtual machine of Thymio II. All descriptions are based on firmware v8.



(a) A typical Aseba network in a robot.



(b) A microcontroller in an Aseba network.

Figure 4.10 – Aseba in miniature mobile robots (image courtesy of [MNM08]).

4.3.1 Aseba

Aseba was developed at the Robotic Systems Laboratory primarily by Dr. Stéphane Magnenat and used in many of our robots. As described on the Thymio & Aseba wiki[3]:

> Technically, Aseba is an event-based architecture for real-time distributed control of mobile robots. It targets integrated multi-processor robots or groups of single-processor units, real or simulated. The core of aseba is a lightweight virtual machine tiny enough to run even on microcontrollers. With aseba, we program robots in a user-friendly programming language using a cosy integrated development environment. Aseba applies to several contexts:
>
> - In multi-microcontrollers robots, Aseba takes advantage of the computational power of peripheral microcontrollers to provide hardware modularity, low latency between perception and action, and economical use of the bandwidth of the robot bus. Moreover, its easy to understand programming language allows fast development of robots' behaviours [MRB+10], [BMRM09].

[3] http://www.thymio.org/en:start

- In education, the easy-to-learn language of Aseba, its user-friendly development environment, and the joy of making a robot move provide an original approach to teach and learn programming [MRBM12], [MNM08].
- In collective robotics, Aseba streamlines the development process by allowing instantaneous changes of the robots code as well as parallel debugging of all robots [MRNM08].

Aseba integrates with D-Bus [6] and ROS, allowing access to microcontrollers from high-level languages.

In the case of Thymio II, as there is only one microcontroller, the main advantage lies in the fact the users can develop high-level programs in a user-friendly environment without being concerned with the low level control details. Working inside the virtual machine, the person who programs can access reliable, safe native functions and local variables with explicit names and documentation and does not risk damaging the hardware. Furthermore, the event-based approach is in our opinion a good way to explore robotics and the sensor-actuator loop concept. When something happens, we decide to react in a certain manner. This kind of logic translates easily into Aseba script, to be observed soon after when testing the robot.

We also had experience with teenagers and children using Aseba. In 2008, for the first EPFL Robotics Festival, Stéphane Magnenat held a programming workshop for youngsters with Aseba Challenge [MNM08]. Aseba Challenge is a simulated environment, where virtual e-pucks have to find food sources to harvest energy. The robot's energy lowers with time, and food sources are not always available. Several virtual e-puck can be in the same simulated arena, and they compete for energy. Participants from 7 to 16 years old learnt programming in Aseba Studio with a short step-by-step tutorial, and could then develop an efficient behaviour for their robot. From this experience we could observe that even children managed to program the robot thanks to the user-friendly Integrated Development Environment (IDE). Its good visualisation and debugging capacities made it intuitive for the users. Thus, we were quite confident to use it also for Thymio II.

The detail of the IDE interface will be given in the next chapter. In the end of this section, we will concentrate on the robot side of Aseba and explain the firmware's architecture.

4.3.2 Firmware architecture

Aseba was developed primarily for multi-microcontroller research robots and its architecture reflects this (see Fig. 4.10). Those research platforms needed primarily efficient exchange of data and flexibility in the number and type of nodes, as well as an intuitive interface and good debugging tool. They did not have "out-of-the-box" behaviours.

In the case of Thymio II, there was only one node, so the asynchronous handling of events lost a bit of its interest, but programming in an event-oriented manner made it very easy to

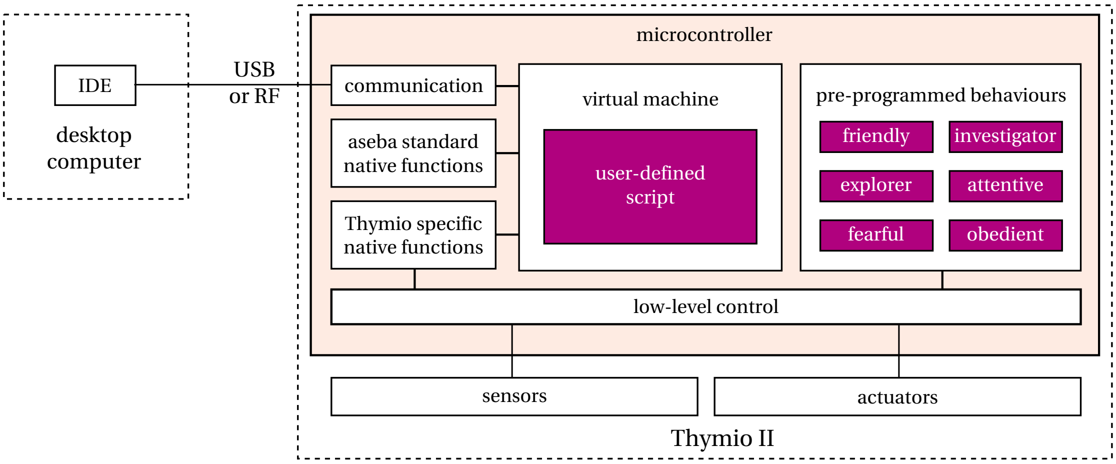


Figure 4.11 – Firmware architecture of Thymio II.

illustrate the sensor-actuator loop. However, this was a product for the wide public, and we wanted a set of pre-programmed behaviours in addition to the Aseba virtual machine. The difference in the architecture is given in Fig. 4.11.

Switching between the pre-programmed behaviours and the Aseba virtual machine depends on whether an Aseba byte-code was written into the flash, or whether the serial port communication was opened. Concretely, if from the pre-programmed menu (see 5.1) one selects the user mode (only present if a byte-code was written into the flash), or if the robot is connected to a computer through USB (or RF if available), it will enter the virtual machine. Once inside the virtual machine, the only way to go back to the pre-programmed behaviours is by restarting the robot.

Low-level control

Timers ensure that sensors are polled regularly, and targets are set. To ensure reliable timing the firmware uses interruptions with different levels. The most sensitive features have higher priorities, and the less sensitive one can be treated with more latency. The priority level is set following the logical sense: if a feature depends on a more primordial one, this one will naturally have higher priority. Table 4.1 lists all priority levels.

4.3.3 Inter-robot communication

In the first versions of Thymio II's firmware, the horizontal proximity sensors were used only for obstacle detection. However, we knew already that it would be quite easy to add the possibility to communicate between the robots. Indeed, the IC module measured only one pulse's duration (maximum 500 µs) every 100ms, leaving a lot of spare time. By adding a second pulse in this free time, we could encode data. This communication protocol was developed by

priority level	function
0	Aseba VM
1	LED behaviour for sensor visualisation, pre-programmed behaviours
2	SD card operations
3	1 kHz timer (user-defined aseba timers, NTC)
4	RC5 communication, accelerometer
5	I2C, USB & RF communication
6	IR sensors, AD conversion (IR sensors, microphone, motors, buttons)
7	Sleep mode

Table 4.1 – Priority levels in the firmware (0 is lowest priority).

Josep Soldevila during a master project in summer 2013, and perfected for release in firmware v7 by Philippe Rétornaz.

We use 16-bits output compare modules to generate the pulses, thus we can count up to 65535 at 16MHz. This means that the maximum time between the first and fourth edge of the signal will be 4096µs. This time will serve for obstacle avoidance and data transmission, and the rest of the 100ms can be spent waiting for reception (see Fig. 4.12).

The encoding itself is simple: when transmitting data, the time between the first and second pulse varies. The intensity and duration of both pulses is identical. The minimum offset between the two pulses depends on the time required to measure the response to the first pulse (obstacle distance measurement). This minimal offset between the pulses corresponds to the transmitted data 0. A certain gain makes the difference between two consecutive values; we decided to encode 11bits. The time between the two pulses can be computed in the following way:

$$time = OFFSET + (GAIN * data) \qquad data \in [0, 2047] \tag{4.1}$$

with a 7'000 cycles offset and a 28 cycles gain.

On the other side, the receiver robot sees two pulses that it did not emit itself. The time between the two rising edged is the same as emitted by the emitter robot, independently of the distance between the two robots or their orientation (see Fig. 4.13). Only the duration of both electrical pulses vary with the distance between robots (but both should keep the same duration), because the intensity of the IR light received varies with the distance (see Subsection 4.2.2). This encoding additionally allows to detect the distance to the transmitting robot (duration of the received pulse) and the direction from which it was seen (by checking which of the seven horizontal sensors received the strongest signal).

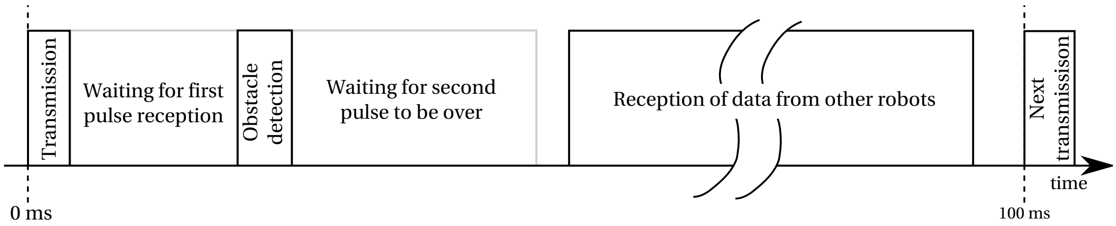


Figure 4.12 – Time usage in the communication protocol.

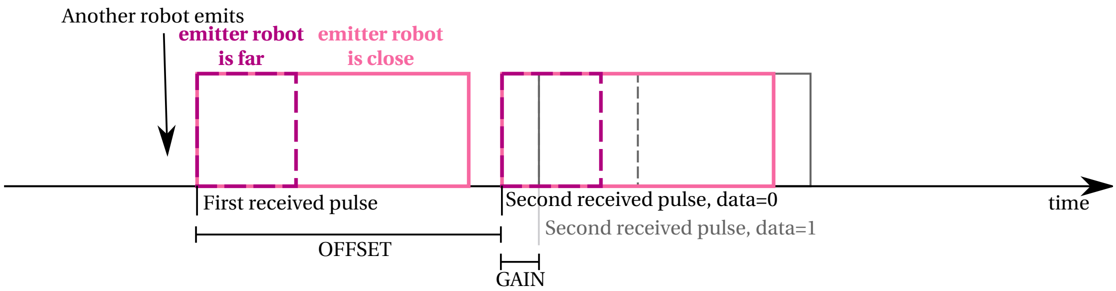


Figure 4.13 – IR data reception in a Thymio II. The time between the two received pulses encodes the data, while their duration give information on the distance to the emitter robot.

Several mechanisms avoid conflicts: when measuring distance and transmitting data, we know the time between the two pulses emitted. If the received pulses have a different offset, or their intensities differ much, then probably another robot emitted at the same time, creating a conflict. The robot will react by changing randomly his moment of transmission. The other mechanism consists in checking when another robot transmits: if it does so very soon after us, we will transmit a bit earlier next time and if it transmits just before us, we will transmit a bit later next time. Like this, the transmission moments should diverge.

4.3.4 Aseba VM on the robot

In this section we give the characteristics of the Thymio II virtual machine. Most of the information mentioned in this subsection is available on the Thymio II wiki[4]. An overview of the Application Programming Interface (API) of Thymio II is given in the cheat sheet available on the website[5] and in Fig. 4.14.

Thymio II specific native functions

The specific native functions concern mainly the LEDs, recording and playing sounds, writing to and reading from the SD card, and enabling the IR communication. There are also hidden system functions.

[4]http://www.thymio.org/en:thymioapi
[5]http://www.thymio.org/en:program

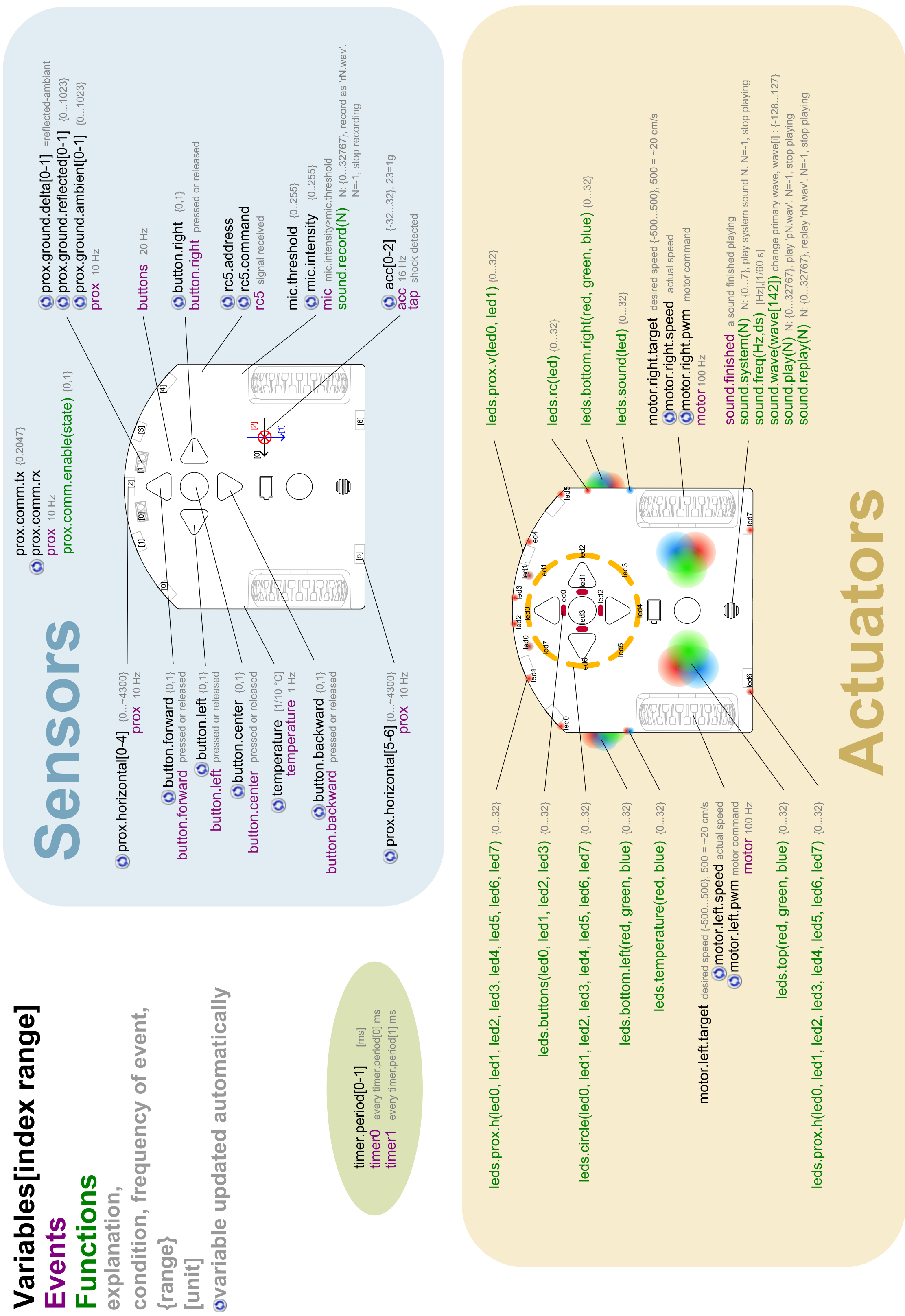


Figure 4.14 – Overview of the API of Thymio II (published in http://www.thymio.org/en:program).

number	function
0	Used to change the maximum sound level. Setting it to 0 mutes the robot.
1,2,3,4,5,6,7	Used to store the minimal value measured on the proximity sensors for calibration.
8, 9	Used for calibration of the motors' speed.

Table 4.2 – Thymio II settings.

_poweroff()
_system.reboot()
_system.settings.read(number, value)
_system.settings.write(number, value)
_system.settings.flash()

Those hidden functions allow to power off or reboot the robot, to read and write the settings. Settings can also be stored in the flash to be reloaded on next startup. The settings are detailed in Table 4.2.

_leds.set(id, brightness)
leds.circle(led0, led1, led2, led3, led4, led5, led6, led7)
leds.top(red, green, blue)
leds.bottom.right(red, green, blue)
leds.bottom.left(red, green, blue)
leds.buttons(led0, led1, led2, led3)
leds.sound(led)
leds.prox.h(led0, led1, led2, led3, led4, led5, led6, led7, led8)
leds.prox.v(led0, led1)
leds.rc(led)
leds.temperature(red, blue)

The first hidden function allows to set the brightness of a precise LED. The other functions allow to se the brightnesses of a group of LEDs at the same time, grouped by their function or location on the robot. For the complete description and location of all LEDs, see Fig. 4.14.

sound.record(number)
sound.replay(number)
sound.play(number)
sound.system(number)
sound.freq(frequency, duration)
sound.wave(wave[142])

These functions allow to record a sound on the SD card with the name Rn.wav (n being the number given as argument), replay it, play a sound recorded on the SD card with the computer under the name Pn.wav, play a system sound (8 available), play a certain frequency and change the basic wave form used for sound generation.

prox.comm.enable(state)

This allows to enable or stop the IR communication between robots.

sd.open(number, status)
sd.write(data, written)
sd.read(data, read)
sd.seek(position,status)

These functions are for handling data files stored on the SD card.

Local Variables

All local variables are given in Table 4.3. Those whose name is preceded by an underscore sign are hidden variables, i.e. not accessible to the users unless they specifically activate the option in Aseba Studio's properties. All hidden variables and functions are either low-level, less intuitive, or potentially dangerous (possibility to damage the robot).

Events

In Aseba, a block of code can be assigned to an event with the keyword `onevent`. The block will be executed every time the event happens. Events are not interruptions; as long as the code has not been executed the next event cannot be processed. Thus, the code should remain short and never contain any infinite loop. All of Thymio II's local events are given in Table 4.4.

Variable name	Size	description
_id	1	node id
event.source	1	event source node id
event.args	32	event arguments
_fwversion	2	firmware version and variant
_productId	1	robot type
buttons._raw	5	raw values of the capacitive buttons
button.backward	1	boolean value the backward arrow
button.left	1	boolean value the left arrow
button.center	1	boolean value the central button
button.forward	1	boolean value the forward arrow
button.right	1	boolean value the right arrow
buttons._mean	5	mean value measured on the buttons
buttons._noise	5	noise measured on the buttons
prox.horizontal	7	horizontal distance measurements
prox.comm.rx._payloads	7	data received on each sensor
prox.comm.rx._intensities	7	intensity of the data for each sensor
prox.comm.rx	1	data received (highest intensity)
prox.comm.tx	1	data to transmit
prox.ground.ambiant	2	measure taken on the ground sensor without illumination
prox.ground.reflected	2	measure taken on the ground sensor with illumination
prox.ground.delta	2	difference between ambient and reflected measures
motor.left.target	2	target speed of the left motor
motor.right.target	2	target speed of the right motor
_vbat	2	voltage measured on the motor H-bridges
_imot	2	induced current of the motors
motor.left.speed	2	measured speed of the left motor
motor.right.speed	2	measured speed of the right motor
motor.left.pwm	2	pwm of the left motor
motor.right.pwm	2	pwm of the right motor
acc	3	acceleration values on the three axes
temperature	1	temperature measure
rc5.address	1	RC5 address of the command
rc5.command	1	command received on the 36kHz receiver
mic.intensity	1	intensity of sound
mic.threshold	1	threshold to trigger the event `mic`
mic._mean	1	mean value on the microphone
timer.period	2	periods (in ms) of the user-defined timers (0: inactive)
acc._tap	1	shock detection

Table 4.3 – Thymio II local variables.

event	description	frequency (Hz)	variables updated
button.backward	back arrow was pressed or released	upon action	button.backward
button.left	left arrow was pressed or released	upon action	button.left
button.center	central button was pressed or released	upon action	button.center
button.forward	front arrow was pressed or released	upon action	button.forward
button.right	right arrow was pressed or released	upon action	button.right
buttons	button values have been probed	20	buttons.backward, buttons.left, buttons.center, buttons.forward, buttons.right
prox	proximity sensors were read	10	prox.horizontal[0-7], prox.ground.ambiant[0-1], prox.ground.reflected[0-1], prox.ground.delta[0-1]
prox.comm	value received from IR sensors	upon value reception	prox.comm.rx
tap	a shock was detected	upon shock	acc[0-2]
acc	the accelerometer was read	16	acc[0-2]
mic	ambient sound intensity was above threshold	when condition is true	mic.intensity
sound.finished	a sound started by aseba has finished playing by itself	when sound finishes	
temperature	temperature was read	1	temperature
rc5	the infrared remote-control receiver got a signal	upon signal reception	rc5.address and rc5.command
motor	PID is executed	100	motor.left/right.speed, motor.left/right.pwm
timer0	when timer 0 period expires	user-defined	
timer1	when timer 1 period expires	user-defined	

Table 4.4 – Thymio II local events.

4.3.5 Data logging on the robot

After the first release of the robot, we came up with the idea of logging data on the robot, thinking that it could be interesting to analyse what the users did with their Thymio II. However, we wanted to protect the users' privacy. Thus, we decided to have automatic activity logs on the robots, but those could only be retrieved by physically accessing the robot and inserting and SD card with a specific file on it. Thanks to this, only people who agreed would give data.

The logging itself consists in counts of different values:

- Total time robot is on, in minutes
- Total time Aseba Studio is connected to the robot, in minutes
- Total time USB is connected without Aseba Studio, in minutes
- Flags (characterising the contents of the byte code loaded on the robot)
- Number of times robot was switched on
- Number of times robot was reprogrammed by Aseba Studio
- Time spent in the menu, in minutes
- Time spent in friendly mode, in minutes
- Time spent in explorer mode, in minutes
- Time spent in fearful mode, in minutes
- Time spent in curious mode, in minutes
- Time spent in obedient mode, in minutes
- Time spent in attentive mode, in minutes
- Time spent in virtual machine mode, in minutes
- Time switched off, in days

One new record is made for each use of the robot. A use session is considered started if the robot is turned on and had been off for at least 24 hours before, otherwise the data is recorder with the previous use. With this data it is possible to understand and characterise a user's activity. The data logging is explained in detail on the website[6].

[6] www.thymio.org/en:thymiolog

4.3.6 Final remarks

We have presented the basic program of Thymio II and the virtual machine that will constitute the user interface through which someone can interact with the robot. All these functions, events and variables, refer to high level functions rather than to purely technical aspects. The advantage of this compared to C programming, for example, is that the robot's hardware is safe, with the user's code contained inside the VM, and the language and API as adapted to the platform, making the programming more intuitive.

When connecting Thymio II to a computer and starting Aseba Studio, the robot's firmware will transmit information about the specific API to the development environment, which will then adapt and correspond to this particular robot instead of listing generic functions. In the next chapter we will present the interaction with Thymio II from the user's side and describe the different interfaces available.

5 User Interfaces for Thymio II

Users can interact with Thymio II and its behaviours in various ways. Out of the box, and without any computer, they can already test the pre-programmed behaviours and discover most of the robot's features. The next step consists in programming the robot. This can be done with Aseba Studio, either with Aseba script or the Visual Programming Language (VPL). In addition, we kept a strategy to show the internal activity of the robot, for instance by placing LEDs next to each sensor, lighting up in order to reflect what is detected. This exists within the pre-programmed behaviours and is also activated in the user mode, as long as the LEDs in question are not required for another function. These different approaches to Thymio II let children of different ages and different interests discover basic concepts of robotics and technology. We expect the youngest users to rather use the simplest interface, while the older ones would rapidly move to text programming. The next sections describe the different user interfaces in order of increasing complexity, somewhat reflecting the order in which users will discover them.

5.1 Basic interface and visualisation of the sensors

When the robot turns on and is not connected to Aseba Studio, it enters menu mode. This mode lets the user select between pre-programmed behaviours, and if any, their own program. The central button activates the behaviours or returns to the menu, with the exception of the user mode, which once started cannot be exited without restarting the robot (see Fig. 5.1). The different behaviours use different sensors and give a small overview of the robot's capacities. In addition, sensor activity is emphasised by the LEDs placed all over the robot's body.

5.1.1 Visualising sensor activity through the LEDs

As explained above, a number of LEDs placed next to the sensors show their activity. Indeed, while it is easy to observe the actions of the actuators (movement, light, sounds), the sensors' activity is not explicit. The idea is to attract attention to the points where sensors detected

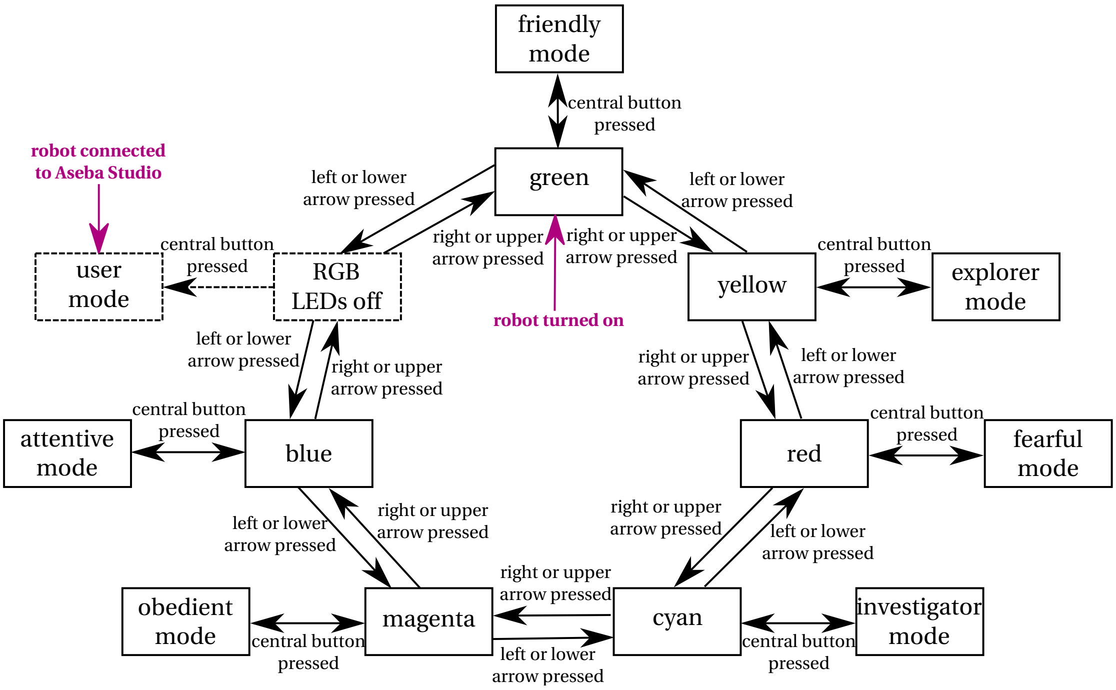


Figure 5.1 – On turning on the robot, users enter the menu mode, described here by a finite state machine.

something and might trigger an event. It is then easier to observe the event - reaction behaviour of the robot and illustrate the sensor-actuator loop.

There are around 40 LEDs that implement this concept. For all proximity sensors, a red LED (two for the front sensor, for the sake of symmetry) lights up when something is detected. The intensity of the light is higher if the detected object is closer. At a constant distance, a more reflective object (white for example) will trigger a more luminous LED than a less reflective one (black). The capacitive buttons' activation is also shown by red LEDs next to them (light on if the button is touched, off otherwise).

A red LED blinks next to the IR RC5 receiver when a code is received. Another one shows communication with the SD card next to the card slot. For the microphone, a blue LED lights up as soon as the sound intensity crosses a certain level. Blue was chosen to avoid confusion with the RC5 LED that is placed just next to it.

The temperature sensor has two LEDs, red and blue, which will light up depending if it is cold (blue), moderate (mix blue and red) or warm (red).

The accelerometer activity (detection of gravity) is displayed on the orange LEDs circle around the buttons. The lowest LED is on, its intensity depending on the inclination of the robot.

All these LEDs' activity is automatic. However it can be turned off when programming, if the user wants to use the LEDs for something else.

In addition, 3 green LEDs show the battery level, and two blue and red LEDs next to the micro USB connector show the charge status. Those cannot be deactivated.

5.1.2 Pre-programmed behaviours

The behaviours are differentiated by names and colours. They use a different set of sensors and give different reactions to their environment. This allows users to discover the different sensing capacities of the robot. It also highlights an important point to understanding the concept of sensor-actuator loop: while the robot's hardware and environment doesn't change during a playing session, its behaviour can be different. The different behaviours represent different programs; at the end, the user will be able to add its own. This represents the central part of the sensor-actuator loop, the controller. The behaviours are very reactive, which highlights the feedback loop concept more than an automaton- or choreography-like behaviour would, because then the robot could seem "blind".

In the next subsections we will briefly describe those behaviours. They kept the ideas of Thymio 1 and were expanded and enhanced.

Friendly

Colour: Green

Sensors used: front IR sensors (detection and communication), ground IR sensors

Already present in Thymio 1

Thymio II waits until it detects an objet in front of it. It then turns, moves forward or backward in order to keep the object in front at a certain distance and centred. It stops if no ground is detected (edge of the table, not placed on a reflected surface, picked up). If another Thymio II in friendly behaviour is seen, they turn to face each other, get close and do a light effect.

Explorer

Colour: Yellow

Sensors used: front IR sensors, ground IR sensors

Already present in Thymio 1

Thymio II moves around, avoiding obstacles. It stops if no ground is detected (edge of the table, not placed on a reflected surface, picked up).

Fearful

Colour: Red

Sensors used: horizontal IR sensors, ground IR sensors, accelerometer

Already present in Thymio 1

Thymio II waits until something is detected, in which case it will move away from the object. It will emit strong noises if it is surrounded, hit, or falls down. It stops if no ground is detected (edge of the table, not placed on a reflective surface, picked up).

Obedient

Colour: Magenta

Sensors used: buttons, IR RC5 receiver

In this mode, Thymio II will move according to the orders received through the buttons or an RC5 signal from a remote control.

Investigator

Colour: Cyan

Sensors used: ground IR sensors

Thymio II follow a black track on white paper, or searches for it if it is not detected. It stops if no ground is detected (edge of the table, not placed on a reflective surface, picked up).

Attentive

Colour: Blue

Sensors used: microphone, ground IR sensors

Added since firmware v3

In this mode, Thymio II obeys commands through sound. When users clap their hands twice, the robot will start moving or stop. If they clap once, it will switch from moving straight forward to turning on itself. If they clap thrice, it will follow an arc trajectory and do a rainbow effect on the RGB LEDs. This mode can be used with a pencil in Thymio II's hole to make drawings. It stops if no ground is detected (edge of the table, not placed on a reflective surface, picked up).

Figure 5.2 – An event-action pair. Here the *Forward button was pressed* event is associated to *Body LEDs display colour yellow* action.

5.2 Visual Programming Language

As explained in Section 3.2.2, a big request from Thymio 1 users was the possibility to program it. We were using Aseba in our research robots; its interface let users access low level functionalities and develop high level code without risk of damaging the hardware through wrong instructions. We also had good experience with children programming simulated e-pucks in Aseba Challenge.

We naturally decided to use it for Thymio II. When the robot was first released, we only offered the pre-programmed behaviours and the script language. We quickly realised the limitations of this approach with young children. While they might understand the concepts of programming, they were not all comfortable with using the keyboard or the mouse. The English keywords were not at all explicit for them either. People asked if a graphical approach would be developed but we had no resources available at EPFL to work on this idea.

Thanks to a collaboration with ETH Zürich however, the Visual Programming Language (VPL) could finally be developed. The first version is mainly the work of Dr. Jiwon Shin, and it was later supported and improved by Dr. Stéphane Magnenat.

5.2.1 Concept

The Visual Programming Language aims at providing a very accessible way for people, especially children, to create a behaviour for their robot. It keeps the event-based approach; it is in fact an additional layer on top of the usual Aseba Studio. Icons on the sides of the interface, later referred to as blocks, represent events and actions. Users can drag and drop them together, forming event-action pairs (see Fig. 5.2). These pairs are checked for errors (duplication of pairs, incomplete pairs or incompatible combinations) and translated into the equivalent Aseba script, which is subsequently compiled. The whole interface is kept as text-free as possible; in addition blocks are animated, for instance to reflect the tuning done by the user, and become more explicit (see Fig. 5.3).

The set of possible instructions is smaller than when writing in Aseba script. Two different levels of complexity give a possibility to start with a very basic interface and then move on to the advanced mode and have more flexibility in the use of the sensors and actuators. The

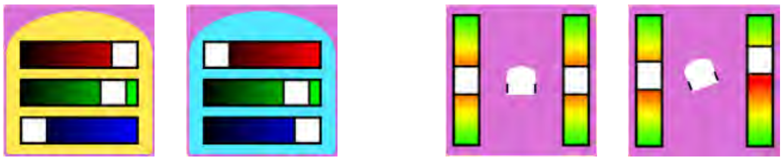


Figure 5.3 – The blocks are animated to reflect the settings chosen by the user. On the left, two configurations of the *top colour* action: depending on the positions of the sliders representing the Red, Green and Blue values, the background colour changes. On the right, the *motor* action block as it animates: in one case both sliders representing motors speeds are in the middle, the robot does not move, in the other case, both sliders are on a forward position, the right one higher, so the animate robot on the block turns left.

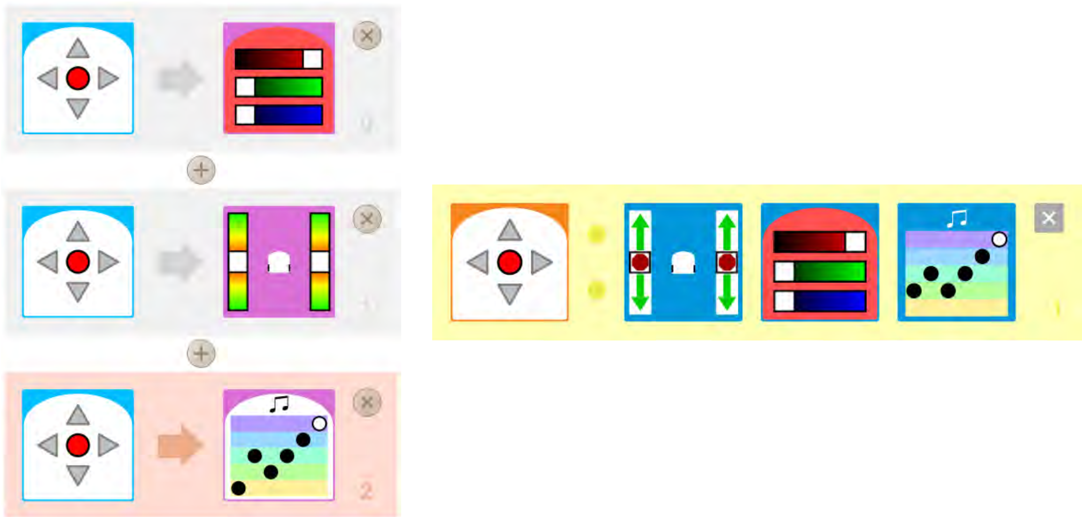
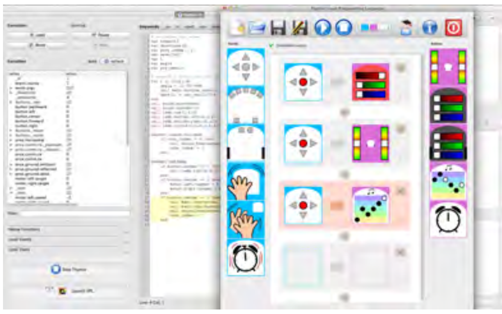


Figure 5.4 – Until Aseba 1.3.3, only one action could associate to an event. Thus, to give the order "when the middle button is pressed, stop, turn red and make a sound", three lines were needed (left). Aseba 1.4 will bring the possibility of associating several actions with an event (right).

advanced mode also introduces variables and lets user store information. When the users want to start using the Aseba script, they can transition smoothly by looking at the code generated by their blocks. The code corresponding to the selected event-action pair will be highlighted in the script window. They can even close the VPL window while keeping their code, and start modifying it directly in the script. Once this is done however, it is not possible to go back to VPL anymore; the translation between VPL and the Aseba script is not bijective.

In the next subsections we will describe the interface and the available blocks of VPL. All descriptions are based on Aseba version 1.3.3. It is at the time of writing undergoing development and should be released later with some improvements, the most important of which is the possibility to have multiple actions per events (see Fig. 5.4).



(a) In Aseba Studio, VPL is a plugin. The Studio window stays visible with the equivalent code behind.

(b) The standalone version of VPL has a side bar with the equivalent code.

Figure 5.5 – Two ways to access the VPL interface.

5.2.2 Interface

There are two ways to access VPL: one is as an Aseba Studio plugin, the other is the standalone version. Both look similar, the difference concerns only the way in which the equivalent script is displayed (see Fig. 5.5). The detail of the main interface is depicted in Fig. 5.6. The central white zone (A) is the code area where pairs are formed. Action and event blocks are available from the right and left side bars (B) respectively. Just above the central zone a line (C) gives immediate compilation output. Errors are further highlighted in the code zone itself. On top of the interface (D), buttons allow to start a new, open or save files. The load and run button sends the byte-code to the robot and starts its execution; a stop button was added because in the beginning the only way to stop the robot was by programming it to do so, and children were often disturbed when realising this. The stop button stops the execution of the code on the robot, but also resets speed targets to prevent it from moving and stops the playback of sound. There is also the possibility to change the colours of the interface, and finally the button to switch between beginner and advanced modes and the help menu.

When switching to the advanced mode, some blocks are modified (proximity sensors, accelerometer), some blocks are added (state) and in the central area a state condition appears for each line (see Fig. 5.7). The state is actually a four bits variable that can be used to store information, create a state machine or set conditions on one or more bits (see Fig. 5.8). The robot itself displays it with four of the eight orange circle LEDs. Once in the advanced mode, it is possible to go back to beginner's mode. However, all information related to advanced-only features will be blindly suppressed, possibly creating compilation errors (see Fig. 5.9).

Figure 5.6 – The main VPL interface.

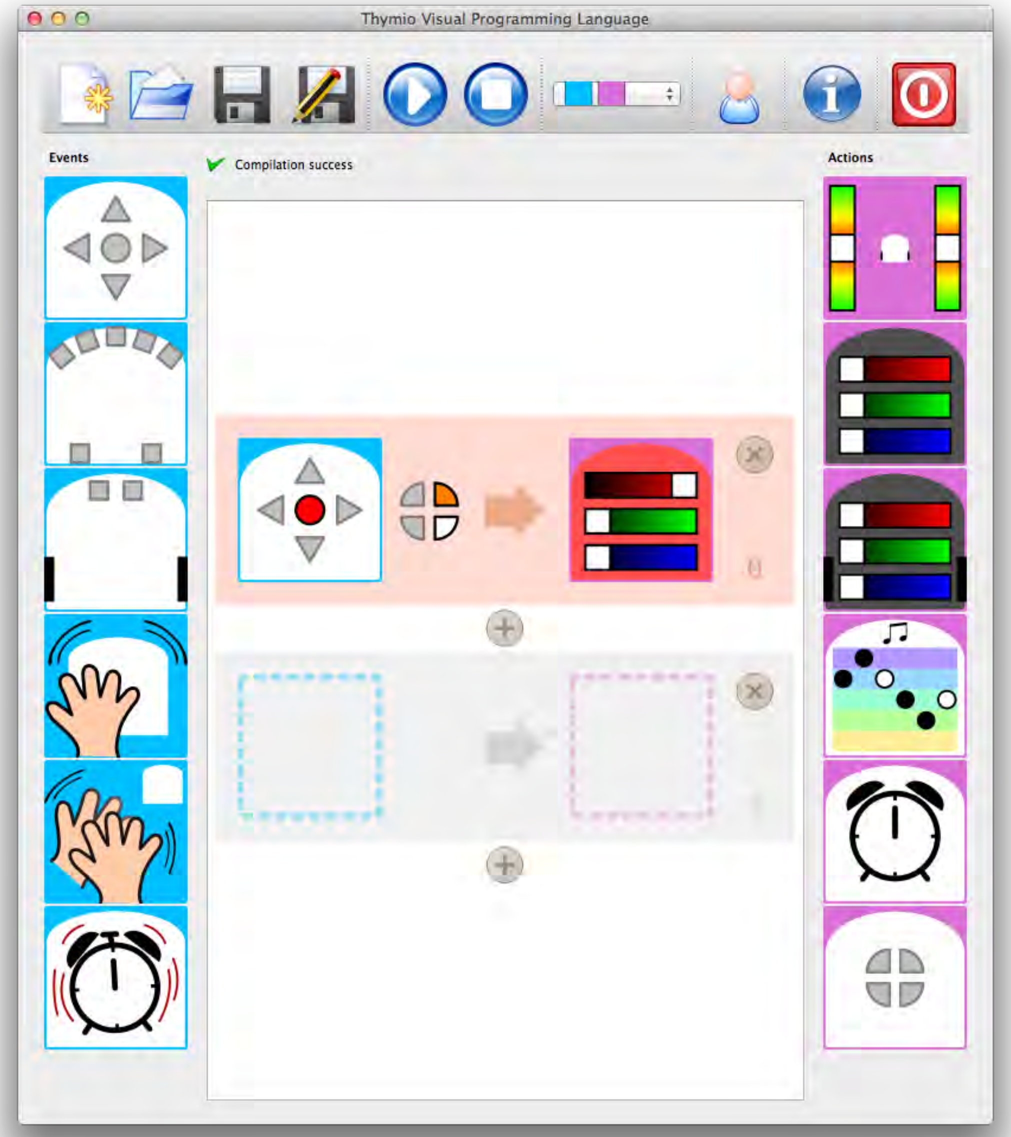


Figure 5.7 – The advanced mode of VPL. A new action has appeared in the right bar, and in the middle zone, conditions can be given to the pairs. The robot has four bit to represent a state: only if those four bits match the condition, the action associated to the event happening will be executed.

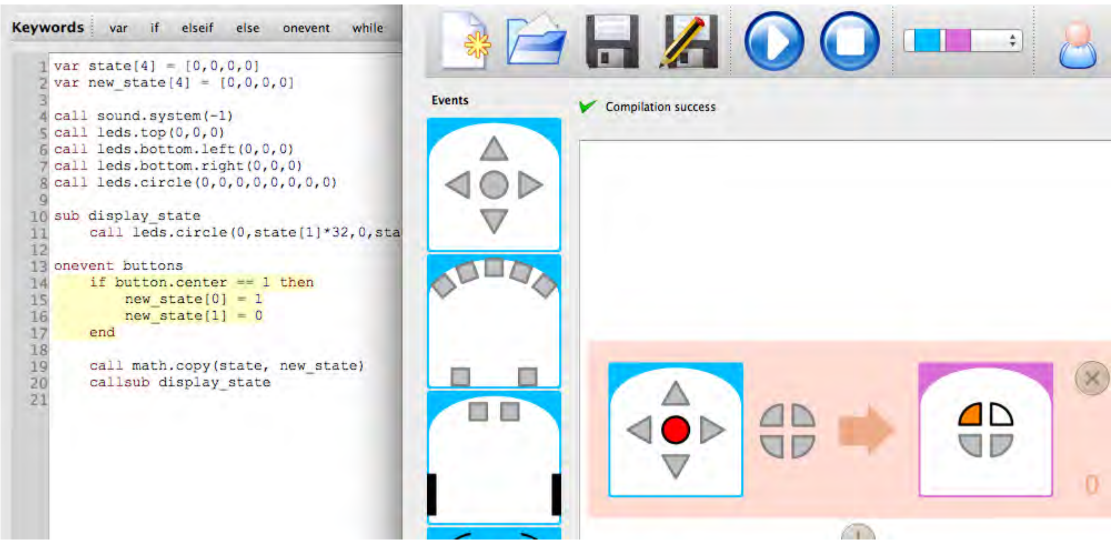


Figure 5.8 – The state variable is represented by four colour circle sections. In the equivalent code we can see it is defined as a variable. On the robot, the circle LEDs will display the state.

Figure 5.9 – As in the example above, when coming back to the beginner's mode in VPL, all conditions are blindly removed, possibly creating compilation errors.

5.2.3 Blocks

In this subsection we give the details of all blocks. The information about VPL is available at the time of writing on the Aseba & Thymio wiki[1].

Buttons

Type: event

This event is triggered when one or more buttons are touched. The equivalent code contains the `buttons` event and an `if` condition, meaning that events will be triggered as long as the fingers stay on the buttons. When selecting more than one button on the same block, the conditions must happen at the same time (logical AND). Red means the button is touched (reminding of the red LEDs that light up to show the activation), and grey means ignore.

Figure 5.10 – Buttons event block

Ground proximity sensors

Type: event

The code generated by this condition is similar to the one produced by the buttons block, but uses the `prox` event. The event is triggered whenever the condition is true, depending on what the ground sensors detect. In this case red means the sensors detect something (table is present or ground white for example) and black means nothing can be seen (robot picked up or placed on a black or non-reflective surface). Grey is again an ignore. For Aseba 1.4, the advanced mode will let users adjust the thresholds for what is considered *white / something present* or *black / nothing detected* with sliders.

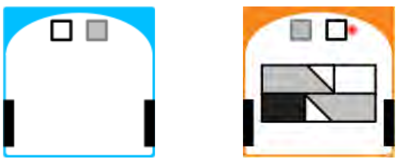


Figure 5.11 – Ground proximity sensors event block, 1.3.1. version (left) and future advanced version (right).

[1] http://www.thymio.org

Horizontal proximity sensors

Type: event

This block is similar to the ground proximity sensor block. The only difference lies in the colours used to indicate the detection state of the sensor on the block. This time red still means something is detected, and reminds of the red LEDs that light up next to the sensors, but white is used when nothing is in front of the sensor. Grey still means ignore. Those colour codes for the proximity sensors have been subject to debate in the community and many different combinations were already tried. Yet another version is currently under development for Aseba 1.4.

Figure 5.12 – Horizontal proximity sensors event block, 1.3.1. version (left) and future advanced version (right).

Accelerometer

Type: event

This block generates code with a `tap` event, that is triggered when the robot receives a shock. For Aseba 1.4.0, the advanced mode will propose three variants of the accelerator block, either detecting shocks (`tap` event), the robot's pitch (`acc` event with condition on the `acc[1]` and `acc[2]` variables) or its roll (`acc` event with condition on the `acc[0]` and `acc[2]` variables).

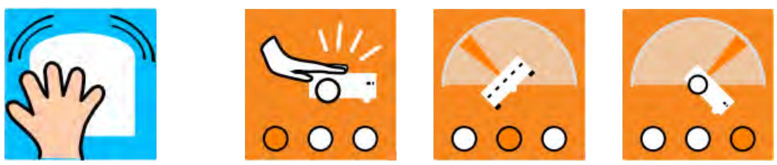


Figure 5.13 – Accelerometer (tap) event block, 1.3.1. version (right). On the left, the future advanced version, with three variants: shock, pitch or roll detection.

Microphone

Type: event

This block is generally referred to as the *clap* event block. The code generated by this block contains the `mic` event, which is triggered whenever the variable `mic.intensity` is higher than `mic.threshold`. In VPL, `mic.threshold` is automatically set at 250. This allows the detection of hands clapping, or of a shock on the robot's case.

Figure 5.14 – Microphone (clap) event block.

Timer elapsed

Type: event

This event only happens if the *timer* action block is used somewhere in the code. This block's equivalent code has a `timer0` event. This event happens only when `timer.period[0]` is different from 0. The period is set through the *timer* action block and set back to 0 once the *timer elapsed* event happened. For instance, a user associates an *timer* action block with a two seconds setting to a *tap* event block, and a *music* action block to the *timer elapsed* event block. This means that when the robot is hit, a music will play after two seconds.

Figure 5.15 – Timer Elapsed event block.

Motors

Type: action

This action lets users set the motors' speeds (`motors.left.target` and `motors.right.target`) with the sliders on the sides. The resulting speed is displayed on the small robot drawn at the centre of the block, which is animated to move with the corresponding speed).

Figure 5.16 – Motors action block.

Top colour

Type: action

This action allows to light up the top RGB LEDs; three sliders set the red, green and blue intensities (equivalent code: `call leds.top(red, green, blue)`).

Figure 5.17 – Top colour action block.

Bottom colour

Type: action

This action is similar to the *top colour* block but for the bottom LEDs (equivalent code: `call leds.bottom.right(red, green, blue)` and `call leds.bottom.left(red, green, blue)`). The difference is marked by two black bars on the sides, representing the wheels of Thymio II.

Figure 5.18 – Bottom colour action block.

Music

Type: action

This block lets the user compose melodies. It has six notes with adjustable pitch (height of the dot on the coloured scale, five different pitches available represented by 5 coloured lines) and duration (white has a duration twice longer than black). The equivalent code uses the `sound.freq(frequency, duration)` function and the `sound.finished` event to play the next note until finished.

Figure 5.19 – Music action block.

Timer

Type: action

This block sets the counter which on timeout will trigger the *timer elapsed* event. The chosen duration can be visualised on the animated clock drawn on this block.

Figure 5.20 – Timer action block.

State

Type: action (only in advanced mode)

This block allows the users to set the four-bits state variable. White means *set to 0*, yellow means *set to 1* (to remind of the colour of the circle LEDs on which the states are displayed) and grey mean no change will be applied to this bit.

Figure 5.21 – State action block.

5.3 Text-based programming

The main interface of Aseba Studio was designed to allow robot users who are not specialists of low-level software to program the robots and access their features while not risking to damage anything. It also provided simple ways to monitor events, to visualise variables and to access the lists of native functions, variables or events (which depend on the hardware), even with multiple-processors robots. Along with the possibility to run the code step-by-step, this makes debugging much easier. The user's ability to monitor what happens during the execution of the program is primordial for the trial-and-error that necessarily happens in robot programming.

Also when learning this trial-and-error process is the basis of the student's interaction. As we saw in the Introduction, when talking about robotics in education, the hands-on, open-ended aspect is very often put forward. Project based learning puts pupils in a position where they have to develop a strategy to attain their goal, because several solutions cans exist. They have to test and evaluate their solution themselves. All of Aseba's tools will come in very handy

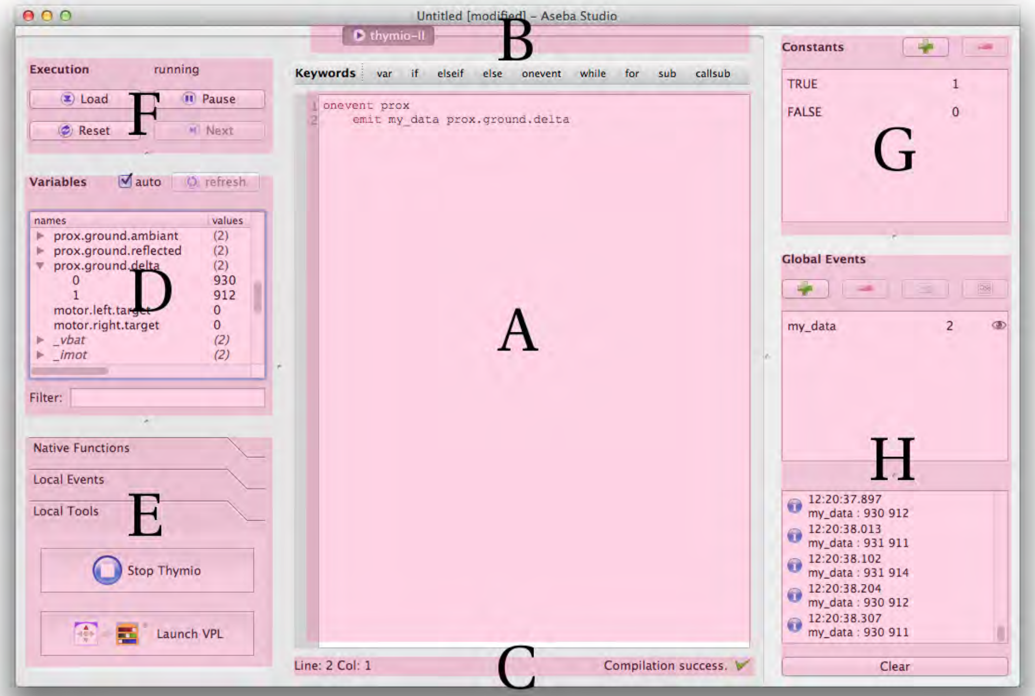


Figure 5.22 – The layout of Aseba Studio. **A**: code writing zone. **B**: nodes. **C**: compilation output. **D**: internal variables. **E**: native functions, local events and tools. **F**: controls (load, run, pause, step). **G**: constants. **H**: global events.

when users need to understand the principles of the sensor-actuator loop. With Thymio II, though it has only one node, this IDE is great because it is easily accessible even for beginners and provides a great overview of the robot features. In addition, Aseba Studio provides the possibility to have translations of the interface and error messages. While the keywords of the language always remain in English, translation of the IDE help the children a lot to understand what is happening.

In the next subsections we will describe the Aseba Studio interface's features and how they make information about the robot accessible. This topic is also covered in the Aseba & Thymio II wiki[2].

5.3.1 Main window layout

The Aseba Studio window is depicted in Fig. 5.22. The central zone (A) is the editor for the script. It provides syntax highlighting, indentation of blocks, and dragging of keywords from

[2] http://www.thymio.org

the other zones. It also shows the current position of execution in step by step mode and colours errors in red. Breakpoints are set by right-clicking on the inspected line.

On top of the editor (B), tabs show the different nodes of an Aseba network. Each node has its own memory, program and execution status. Thymio II has only one node, as it has only one processor.

On the bottom of the editor (C), the compilation output line gives in real time the success of the compilation or description of the error in the code. Those messages are translated to correspond to the interface's language.

On the left, the memory window (D) lists all internal variables, that can be refreshed automatically. Just underneath (E), all native functions and local events are listed. They can be dragged and dropped into the editor zone, and a short documentation appears when the mouse cursor hovers on top of them. In addition, there can be local tools such as the VPL for Thymio II or the stop button.

Above the memory window (F), buttons allow to load the code into the robot, start/stop its execution, reset it or execute one instruction in step-by step mode.

On the right, the upper zone (G) allows to define constants. The middle and bottom zones (H) let the user define network-wide events and monitor them. These events happen when the command `emit event_name arguments` is executed. They can carry arguments and only the other nodes can receive it. In the case of Thymio II, as there is only one node, network-wide events are useful only to send values to the computer to draw a plot.

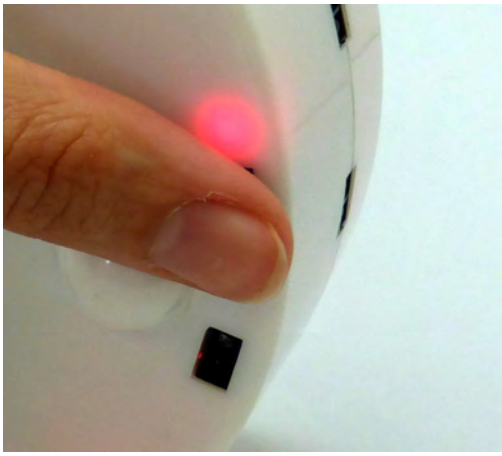
5.3.2 Monitoring variables and plotting them

When teaching robotics or programming to children, the possibility to efficiently explain the concept of variable makes a great difference. By itself, the concept of a variable might appear abstract, but illustrating it in different ways give it a sense of reality. With Aseba and Thymio II we provide several ways to visualise internal variables.

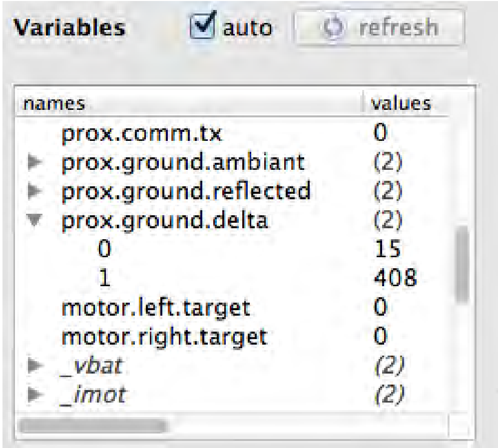
First of all, those variables that represent a sensor value are displayed by LEDs on the robot, as explained in Section 5.1.1. Children can simply take the robot in their hands, approach a finger and see the LED light up (see Fig. 5.23a).

Then, when programming, if they want to put a condition on one of ground sensors for example, they will need to know which numerical value corresponds to the distance they want to measure for example. Thanks to the memory window, they can easily put the robot in the condition they want to recognise, and observe the numerical values changing in the memory window (see Fig. 5.23b).

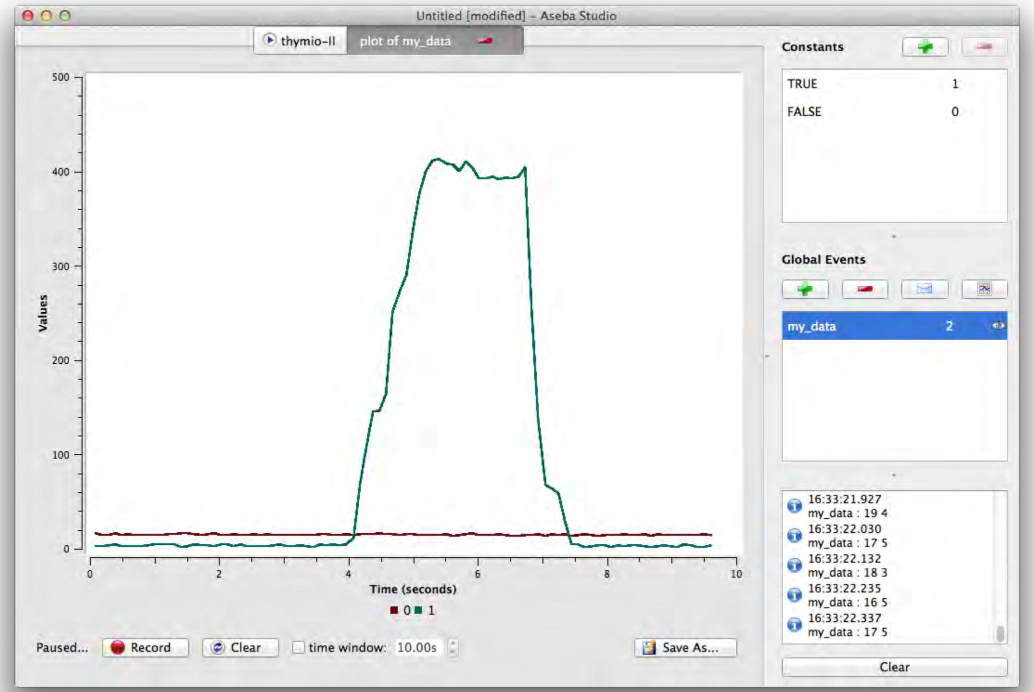
Finally, to observe a variable that changes with time, or that may have a bit of noise, a wider overview than just an instant value is preferable. Aseba Studio provides the possibility to



(a) The finger in front of the bottom sensor lights up the LED.



(b) In the memory window, one can observe the values changing.



(c) With an Aseba plot, one can easily get the notion of time and see the value change. Here, the finger covers the sensor after four seconds and is removed three seconds later.

Figure 5.23 – Thymio II and Aseba Studio give different means of visualising variables.

plot network-wide events. Thus, one can very easily create an event, give it the number of arguments needed (for example, two arguments to observe the ground sensors' values), and emit it regularly with the values of the observed variables (see Fig. 5.23c).

5.3.3 Keeping the information accessible

For beginners, understanding the Aseba language might seem like a lot of keywords to remember, especially since the native functions and local events are hardware-dependant. The whole IDE is designed to help with this issue, so that users can concentrate on the behaviour they want to create and not waste time searching for information.

The main statements of the language can be dragged and dropped from the top bar, the native functions and local events and variables from the left side widgets. Information about their usage appear on mouse-over. In addition, auto-completion adds for example the `call` keyword when dragging a function name.

From the help menu, one can easily access the wiki contents, even when offline, with reference cards, documentation on the language and the Thymio II API etc.

5.3.4 Limitations and possibilities for future developments

One limitation of this interface comes from the fact that the hardware-dependant native functions, local events and internal variables are coded in the robot's firmware. This means that Aseba Studio needs to be connected to a robot to provide all this information. As soon as the robot is unplugged, the left-side widgets will disappear from the interface, and while one can still edit the code, the compilation cannot happen. This also means that Aseba Studio will not start unless a valid target is present.

For schools, it might be useful to have the possibility to work on code even without the robot. A first prototype of a Thymio II simulator was created during a semester project by Nicolas Dinh; its development should continue towards a stable version that could be released in a future version of Aseba. While the simulated robot will be less interactive than the real one (it will not record sounds or encounter slopes or holes), its API is exactly the same, so the code developed when using it can be transposed to the real robot directly.

5.4 Comparison with the state of the art

We have described in this chapter and the previous one our own robotic platform for education. In Chapter 2 we saw that the most popular platforms in schools were the Lego kits and the Bee-Bots. We also saw characteristics of the programming interfaces for children: using high level notions, and avoiding text if the target audience is really young. In respect to this, our platform is also commercially available, proposes a text-free visual interface as well as a more advanced text-based development environment, and high-level functions and variables. It does not allow to build the electronic aspects and it is not modular, even though construction and flexibility of use are promoted in other ways. As a wheeled robot, it would fit well as an object of learning or a tool, and could be used in several topics, though we had especially introduction to technology in mind. In addition, it has some unique features:

- A low price compared to Lego Mindstorms
- Both pre-programmed and custom behaviours
- Adapted for very young children but not limited with respect to the sensing or actuating capacities
- Feedback of the internal state directly on the robot
- Progressive interfaces to offer increasing complexity as the learners grow

In the next chapter we will focus on its deployment in outreach events and in schools, and evaluate its potential as a teaching tool.

6 Impact of Thymio II

In this chapter, we will retrace the diffusion of Thymio II, from it first production and deployment to the current day. We will give a quick overview of the occasions in which it was demonstrated to a wide public and the collaborations it generated, before we move on to the analysis of its impact. Our goal is to evaluate whether robots, and Thymio II in particular, make good educational tools, and to understand what are the reasons for its adoption or rejection by users in general, and teachers specifically. Once our research topics are defined, we will list our different data sources and explain how they were collected. In the final part, we will refer to these data sources to answer our questions.

6.1 Deployment of Thymio II

Going form the first idea of a robot to finally testing it at a large scale with children is a long work. In this section we will describe the process of going to production and deploying a robotic platform.

6.1.1 Bringing a research robot to production

From the beginning, Thymio II was intended to be mass-produced and distributed widely. Therefore the development had to take this into account at an early stage. Constraints arose that were not usual in the development of research robots, mainly related to the limitation of costs, availability over a long period of components (for future production batches) and security requirements (CE toy certification) on materials use, access to the electronics or indications on the packaging. Every production step had to be anticipated, for example the mounting order and procedure had to be prepared, and the plastic parts were designed according to the constraints of plastic injection.

After the first prototypes (PCBs and rapid prototyping for the plastic parts) made at epfl were convincing, we proceeded to make prototypes with our partner for production in China. At this stage we ordered only small amounts of components and produced a small series of PCBs

(10 pieces) that we tested. The injection moulds were made and we received the first plastic parts for adjustment (colour, fitting with Lego bricks, small shape corrections). We prepared a detailed mounting procedure with pictures showing all stages of assembly, as well as a programming and test procedure to check that there were no problems with the electronics. The author went directly to the production facilities in Shenzhen for this stage; it was easier to react and detect problems in the first units produced. This also allowed to identify problematic steps in the production for improvement in the next batches. For example, the cables for the motors, battery, and loudspeaker were difficult to handle once soldered, thus connectors were added to the design.

In the next step, we produced a series of 100 robots with the same production line as would be used for all robots. Some problems could be corrected at this stage and we found particularly useful to keep a list of key points for the quality, with examples of what is correct or wrong. For instance, the right shade of plastic was not obvious through a simple description for the producer, but once good samples were produced they were kept as reference. This approach of making first a few prototypes, then 10, then 100 units was kept when a new producer was chosen and it proved efficient, as well as the mounting, programming, test procedures.

After this, the production line was ready, and the nonprofit association *Mobsya*, founded by former and current members of our laboratory, launched the production of the first batch of 1'000 Thymio II in winter 2010-2011. The technology transfer and first production stage were supervised by the EPFL team, and the open hardware nature of the project reduced costs and time to production for *Mobsya*, while giving the laboratory an opportunity to have its robot in large quantities and to reach a broad public.

6.1.2 Distribution

The first batch of a few hundreds of robots arrived just in time for the 2011 Robotics Festival at EPFL, where they were distributed in several workshops.

The *EPFL Robotics Festival* took place each year in the spring from 2008 until 2013. This event consisted of robot exhibits, shows, and workshops covering an array of topics, from soldering electronics and building lamps in handicrafts, to programming on several robotics platforms. The attendance grew every year, from 3'000 people in 2008 to 17'000 in 2013, with 2'200 workshop places available. We already had experience of workshops with children at the Festival [RRB+11], [MNM08], thus it was an ideal launching platform for Thymio II.

This was the first occasion for people to buy Thymio II. A fee of CHF 60 was demanded for the workshops, after which participants could keep the robot. We held two programming workshops (beginners and advanced) and one handicrafts workshop, totalising 300 workshop places in one day. In addition, *Mobsya* sold robots directly at their sales booth and ran quickly out of stock, bringing the number of robots distributed that day to more than 400. In parallel, we set up a community website in the form of a wiki. It contained the basic information about the robot, how to start using it, along with the tutorials used in the workshop and a forum for questions and exchanges. All specifications (schematics, gerber files, CAD design) were also made available under a creative commons license. In addition, the website provided information about the open-source software Aseba, as well as downloadable installer packages.

After this first public appearance, Thymio II has been produced regularly by Mobsya and used at many different occasions. Until now, more than 5'500 units have been distributed by Mobsya (in Switzerland, US, France....), among them more than 900 to schools (mostly in Switzerland and France). Apart from the sales booth at the Festivals, Mobsya has an online shop and several resellers. Although the project is open-hardware, it seems no other company has ventured yet into producing it. In the yearly festival, we kept proposing workshops with different topics and recommended ages. In 2012 two different workshops were held: one "play and robot discovery" workshop, where young children learnt about robotics through interaction with the pre-programmed behaviours and one more advanced workshop with text-based programming. It totalised 380 workshop places. 2013 was the first time the Visual Programming Language (VPL), developed during the summer before, came to the festival, and we tried to offer a wider choice of activities with five workshops. Two of those, based on playing and discovering the robot through the pre-programmed behaviours, addressed the youngest age categories. One workshop, based on VPL, allowed to start programming in a more friendly way than the text-based interface used the previous years. Finally, two text based programming workshops were offered to older children and teenagers: one for beginners, based on a tutorial and explanations, the other for experimented users, with a quick reminder of the programming syntax followed by challenges to solve. This allowed us to welcome up to 508 children in a day.

6.1.3 Collaborations

The Thymio II project triggered several collaborations with external partners. In the summer 2012, the first version of VPL developed by Dr Jiwon Shin and Dr Stéphane Magnenat (former member of our group) of the ETH Autonomous Systems Lab (ASL) was tested in a class, followed by improvements and new tests made at Scientifica 2012 in Zürich. The Zürich team has since then taken part in several other outreach events and organised more workshops to test VPL in real conditions. They also developed a contact with Prof. Mordechai Ben-Ari, a specialist of computer science education from the Weizmann Institute of Science in Israel. Thanks to him, VPL could be improved and tested in more details.

A parallel effort was made to get in touch with schools. After a first contact with the teacher training school of Lausanne (HEP Lausanne), we provided support in a course they gave about handicrafts and robotics, and took part in some events they organised like *Cafés pédagogiques*. *Cafés pédagogiques* consist in afternoons where teachers meet around coffee to discuss a topic and share their experiences in an informal manner. This gave our platform more visibility among teachers and also provided us with some feedback about their impressions.

We furthered this effort by setting up *Robots en Classe*, regular training sessions for teachers in technology-related topics, like programming or electronics. Some of those sessions have concentrated on Thymio II.

After that, some teachers started using robots in their classes; however we still had the impression that they were only pioneer teachers, sort of geeks driven by their own interest in the topic. To understand better which teachers would use Thymio II or other robots in their classes, and why, we started several collaborations. One was with Morgane Chevalier, also from HEP Lausanne and then integrated part-time in our team, who had previously specialised on the pedagogy of Information and Communication Technologies (ICT) and Media. With her help we tried to apply models of evaluation of computer-based environment for human learning to robotic platforms. The other collaboration we initiated was with Professor Farinaz Fassa and her team, from the University of Lausanne (Unil). Specialised in sociology and gender issues, they investigated the acceptance of and attitudes towards robots.

6.1.4 First feedback from the users

During the Festivals, the attitude of the public was very positive and enthusiastic. The participants seemed satisfied, and some came again year after year, sometimes bringing their robot again, sometimes buying a new one. Some also mentioned coming because a friend or sibling had told them about the workshop and they wanted to try. Teachers also told us that some children had brought their robot in class after the event, to demonstrate what they had done. The programming part was well received by children, but adults often expressed concern that it would be too difficult for youngsters.

However, we still had doubts whether workshop participants used their robots once alone at home. For example, we noticed that children who came back to the workshop were not much more confident with the programming interface than the others. Also, when they brought their own robot (4-5 cases), the batteries were generally empty, and they had not done any firmware upgrade. On the forum, at first we saw some troubleshooting questions or requests for help to install the software, but few recurring users or messages denoting a deeper use of Thymio II. Finally, there started to be a few interested people who asked quite specific questions about Aseba, obviously adults. In one attempt to encourage people to share their experience with the community, we organised a contest, where we asked for any contribution with Thymio II, be it a photograph, a drawing, a video or an example program. The winner would receive a Lego box. We sent the announcements via the Festival database (hundreds of addresses), but had no participation to this contest.

In schools, we noticed that Thymio II became quite popular in primary schools, where it was used in parallel with the Bee-Bot for occasional activities. Generally the activities consisted in discovery of robotics involving play with the pre-programmed behaviours. After VPL was released, some teachers, generally those responsible for the IT in their schools, did programming.

In high schools, Thymio II served mostly for the Computer Science complementary option[1] though not over long periods (three sessions of two hours at most to our knowledge), or for the Maturity work that each pupil has to submit in order to obtain their baccalaureate. In that case, the work was more independent and project-oriented; until now we have heard of 14 cases. Another example of use was during a special thematic week, in combination with Lego Mindstorms.

Most of those teachers asked us for support in their projects. For example, in the case of a computer science course, the teacher asked for ideas to prepare exercises, and together we came up with a series of increasingly difficult challenges that the robot had to solve. He then did a session with the wiki tutorial, a session with the challenges and a more open, creative final session. For the Maturity works, we were asked to be experts for the validation. The pupils had no real courses and had to find information by themselves on the wiki, or they could contact us, which they never did. For the thematic week, the teachers asked us to come and make a presentation, but were ill prepared themselves. The teachers asked the pupils to follow the tutorial but were uneasy answering their questions.

Between primary school and high school we found less contacts, though one teacher decided to use Thymio II occasionally for German lessons. We were told that the topics were separated, not allowing for interdisciplinary, exploratory activities like playing with Thymio II, yet were also not specific enough to go into the details of programming.

On the wiki side, we started having contributors who did mostly translation work. We were hoping that users would share their creations and experiences, but very few contributors added content. We prepared a special section for teachers to share their pedagogical material, but this too did not meet much success. People told us that the wiki looked too complicated and that they did not find the information they were looking for. Several times, we were asked for content that was already available; for example a teacher stated that "it is too bad that there is no step-by-step tutorial that provides an overview of the robot's possibilities", which actually existed at the time of the complaint. We suspected that either the wiki was not engaging and clear enough, or that this was an old complaint: this person had bought a robot one year before, gave a look at the wiki (at a time the tutorial was not yet available) and not gone back to it since.

With time though, we started to see a few people making movies and posting them on Youtube.

Overall people liked the robot but seemed to consider it time consuming to implement. They would have liked to use it more, but did not find the right occasion. When they did invest time, some obstacle prevented them from going further or building something they found worth sharing. On their own, they might not have known where to start, not felt confident to achieve something by themselves or simply not found the required information. It appears crucial

[1] In Swiss high schools, pupils have some mandatory courses, choose the third language and two optional courses: specific and complementary. Computer science is one of the possible complementary options, corresponding to a two-periods lesson per week.

that the first steps they take when venturing into robotics are well accompanied, to gain a minimal level of confidence before doing something on their own. All these considerations and feedback helped us shape more precise questions for the evaluation of Thymio II.

6.1.5 Research topics

Thymio II perceived by different age and gender categories

When defining the requirements in the conception of Thymio II, we knew we wanted a robot that would be as interesting and usable by young children as by teenagers or young adults, though this is opposite to the philosophy present in the toy industry. We also wanted it to appeal to both genders. Did we meet our goal? Do users of all ages and both gender find Thymio II interesting and motivating? In what are their expectations different, and can Thymio II address them? Answering those questions would give precious information about the acceptability and the usability from the point of view of the pupils.

What do children actually learn?

We also wanted to validate the robot as a pedagogical tool. The core aspect is the utility: we wonder then, how well users really acquire knowledge. How well do children manage to understand such concepts as the sensor-actuator loop, variables, or events?

Is the sensor visualisation efficient?

One of the unique features of Thymio II is the presence of LEDs next to each sensor. Does the sensor visualisation really help pupils in grasping the functioning of the sensor? Does it attract attention, and is this beneficial or detrimental to learning? Is this visualisation used consciously when planning a behaviour for the robot?

How is Thymio II used once at home? Is Thymio II adopted by the schools?

Finally, we wanted Thymio II to sustain interest both in homes and in schools. Do children use Thymio II frequently after a first experience in a workshop, or forget it like Thymio 1? In schools, did Thymio II successfully manage to find its place as a tool for education? What are teachers' expectations of robotics? What motivates or blocks them to adopt a new tool in class or to decide to opt for robotics? While a platform might seem usable and acceptable from the point of view of a pupil, it is crucial to understand these factors also from the teacher's side.

In the next sections, we will first go into more details of how and when we collected different data, before using these sources for the analysis of our questions.

6.2 Sources of information and methodologies used

We had many different occasions to collect data since Mobsya started to distribute Thymio II. The Festivals especially were great occasions to make observations and surveys. We also used our contacts in schools to interview teachers and collect their opinions. All our data sources are given reference codes and shortly summarised in Table 6.1. We will describe them in more details in the next subsections, before moving on to the analysis of the data itself.

Reference code	Type of data source	Occasion	Sample size	Respondents
CHILIEXP14	Experiment	In 2014, a semester project was conducted at CHILI to investigate the effect of the sensor visualisation with eye-tracking technology	52	EPFL students, aged 17 to 22, 25% women
ETHSURVEY13	Post-test to measure the learning of CS concepts with Thymio II and VPL	Three workshops were organised in Lausanne and Zürich to test whether users acquired some concepts of CS	50	a group of 30 girls and 10 boys, aged 10 to 15, and a teacher-training class of 8 women and two men, aged 22 to 30
POLYTHEME13	Survey about motivation and appreciation of the activities, data logging on the robot	In January 2013 a *Polythème* workshop was organised by the Equal Opportunities Office: 3 afternoons of programming with Thymio II	17 (surveys) 7 (logs)	11 girls and 6 boys, aged 12 to 14
SCHOOLDAY14	Survey about perception of Thymio II and Lego Mindstorms	Class visit day at EPFL	275	133 girls and 139 boys, aged 10 to 14
SUBFESTXX	Workshop subscriptions database	EPFL Robotics festival in 2012 and 2013	376 (2012) 498 (2013)	Participants to the Thymio II workshops: 171 boys, 92 girls,113 unknown (2012) 215 boys, 111 girls, 172 unknown (2013)
TEACHERSURVEY11	Survey on teachers' satisfaction	Teachers could subscribe as assistants to the 2011 Festival's workshops in exchange for robots and written material.	16	Teacher of different education levels (primary, secondary, baccalaureate, teacher-training)

Reference code	Type of data source	Occasion	Sample size	Respondents
TEACHERSURVEY14	Survey to investigate the utility, usability and acceptability of Thymio II in schools	A survey was sent to teachers who took part in the *robots en classe* or *café pédagogique* courses	25	10 men and 15 women teaching at different levels (primary, secondary, baccalaureate, teacher-training)
UNILSTUDY14	Series of interviews	Unil researchers in sociology interviewed teachers to investigate the gender differences and the obstacles or encouragements to the use of robots in school	15	8 women and 7 men teaching at different education levels (primary, secondary, baccalaureate, teacher-training)
WSSURVEY11	End questionnaire to evaluate Thymio II and the programming workshop	During the 2011 Festival, participants to the programming workshop were asked to fill the questionnaire at the end of the session	116	91 boys, 22 girls, 3 unknown, aged 8 to 14 (3 exceptions aged 15, 18, 44)
WSSURVEY12	Pre- and post-tests, with two experimental conditions (with and without sensor visualisation) to monitor participants' learning and evaluate the impact of the sensor visualisation	At the 2012 festival, participants filled questionnaires at the beginning and the end of the programming workshops.	165	32 girls, 88 boys, 45 unknown, aged 8 to 14
WSSURVEY13	Survey to evaluate Thymio II's potential with different age groups.	During the 2013 Festival, in five workshops using Thymio II, with different activities and focuses, participants filled a questionnaire at the end.	286	200 boys and 86 girls aged 4 to 18

Table 6.1 – Information sources for the evaluation of Thymio II.

6.2.1 SUBFESTXX: Festival subscription data

For each year, we have subscription data: number of attendants, and generally gender and age. People can subscribe for workshops in advance or on the day itself. Often, gender and age data is available only for advance subscriptions, because on the day itself, the data is not entered in order to gain time.

This will be referred to as SUBFESTXX, XX being the year, in the rest of this work.

6.2.2 Thymio II workshop surveys

Thymio II workshops were held on several occasions, in particular at the annual EPFL Robotics Festivals, but also on occasions like outreach event or special training in classes. Those were good opportunities to gather data from the users, in order to improve our robot and its user interfaces. Especially the Festival workshops attract high numbers of participants. However, the pace of the day is too frantic for really controlled experiments and systematic, qualitative observations. We could still conduct several surveys, which will be detailed below.

WSSURVEY11: Survey during EPFL Robotics Festival workshops in 2011

In 2011, Thymio II was released just in time for the Robotics Festival in May. During the day of the Festival, we held workshops to learn how to program with Thymio II; no user had ever tried it, though some knew the first Thymio, which could not be programmed. There were 4 sessions of 1 hour 20 minutes each, with a capacity of 39 children per session. There was strong coaching presence with one assistant per 3 attendees. Sessions started with a short introduction to robotics, and then participants followed a tutorial at their own rhythm. They used Aseba with the text-based language.

At the end of the workshop, participants were asked to fill a questionnaire to measure their understanding of some important concepts of computer science and robotics. In total, 116 participants answered. Most were children between 8 and 14 years old, two did not give their age, and one was 44. There were 91 boys, 22 girls, and 3 unknown. The proportion of girls depends on the age, as shown in Fig. 6.1. The conclusions drawn from this questionnaire, along with the detail of all the questions, were published in [MRBM12] (questions also available in Appendix C). This was a joint work between our group, Dr Stéphane Magnenat of the Autonomous Systems Lab at ETH Zürich, and Dr Michael Bonani of Mobsya.

The population encountered in festival workshops has a bias. First, only motivated participants come, as it is not part of an obligatory school program. Secondly, we know from SUBFEST13 that the adult visitors of the festival mostly have a higher education background, so their children are not representative of the general population.

This survey will be referred to as WSSURVEY11 in the rest of this work.

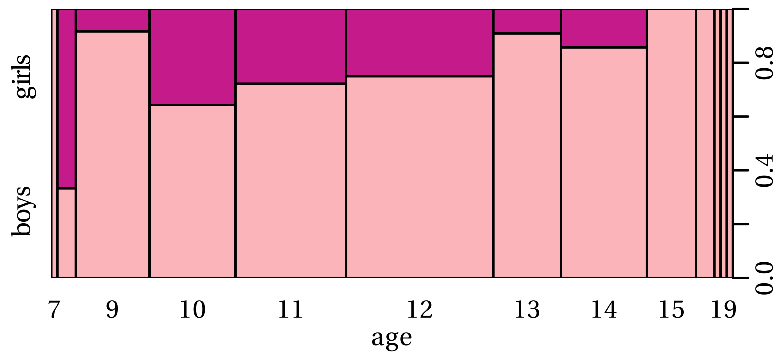


Figure 6.1 – WSSURVEY11: Distribution of age and gender in the 2011 Thymio II workshop (n=116, data published in [MRBM12]). Gender correlates with age (p-value=0.04).

WSSURVEY12: Survey during EPFL Robotics Festival workshops in 2012

In 2012, two workshops with Thymio II and text-based programming were held. We took this opportunity to measure whether the presence of the sensor visualisation influenced the children's learning. There were five sessions of one and a half hour during the day, with two rooms having 20 places each. There were assistants to coach the participants: one for two children. The content of the workshop was the same in both rooms and in all sessions: after a short introduction, participants went through a tutorial at their own pace. A questionnaire was given at the beginning and at the end of the workshop, with questions about what a robot is, what sensors do, what is an `if` used for, among others (for the complete questionnaire see Appendix E). Assistants were asked not to help the children with filling the questionnaires.

Two questions concerned the sensors. Our hypothesis was that the visualisation through LEDs (see Section 5.1.1) would influence the participant's answers to these questions. In order to measure this, two different sets of robots were prepared for the workshops: one with a normal behaviour including the sensor visualisation, the other one with the sensor visualisation deactivated. Participants and assistants would not be told about this difference, only the two responsible people knew. One room would have the robots with visualisation, the other without. In the middle of the day, we exchanged the two robot sets to avoid measuring a difference due to the teacher.

In total, 184 participants answered the beginning questionnaire, and 182 the end questionnaire. We could link the pre- and post-questionnaires answers thanks to the subscription number, and ended up with 165 complete entries. Out of them, we could obtain gender and birth year details only for 84, from the Festival subscriptions (SUBFEST12). This is due to the fact that this information was given when subscribing to the workshop, either in advance (half of the workshop places available, form to fill online) or on the day itself at the welcome desk, in which case the welcome staff would often omit filling these fields to gain time.

Overall, we had 87 respondents in the workshops with sensor visualisation (8 females, 57 males and 22 unspecified), and 78 in the workshops without (24 females, 31 males, 23 unspecified). The proportion of girls was significantly lower in the workshop with sensor visualisation (p-value=0.0001), so there might be a bias, though not for sure as not everyone's gender is known. However, we consider that gender should not influence the understanding of the concepts presented during the workshop, but could have influenced the prior knowledge of the field. Ages ranged from 8 to 14, with a peak around 9 and 10 year-olds, and only three answers from participants older than 14 (15, 18 and 47).

The population encountered in festival workshops has a bias. First, only motivated participants come, as it is not part of an obligatory school program. Secondly, we know from SUBFEST13 that the adult visitors of the festival mostly have a higher education background, so their children are not representative of the general population.

This survey will be referred to as WSSURVEY12 in the rest of this work.

WSSURVEY13: Survey during EPFL Robotics Festival workshops in 2013

In 2013, we decided to focus on age differences in the use of Thymio II. We proposed five different workshops, for different age groups, with different goals and challenges. Our goal was to adapt the activities and materials to each group, with the same robot. This way we could have a wider range of participants, and understand better the motivations and specificities of each group. This survey has been reported in [RCMM13].

The five different workshops are summarised in Table 6.2. In the rest of this chapter, we will refer to the workshops through their short identifiers A, B, C, D, and E; their full titles are available in Table 6.2. They were organised with the help of Monica Prieto, Morgane Chevalier, Dr Stéphane Magnenat and Laurent Michel. As usual in the Festival workshops, there was strong coaching in the different activities, with generally one assistant for two or three children.

Two workshops, A and B, used the pre-programmed behaviours and accessories to create an activity. In A, participants discovered how Thymio II could react, and in B, it was used to solve tasks. One workshop, C, focused on graphical programming with VPL, with a short introduction followed by programming tasks. The two last workshops, D and E, focused on text-based programming. Both had a short introduction to the language and to the robot, but D was intended for beginners, following a tutorial, while E welcomed more advanced programmers with complex challenges.

All workshops were nearly full and participants mostly followed the advised age. In all workshops, we asked the participants to fill questionnaires where we asked about their motivations to come, their appreciation, and their perception of certain notions. All the questions but one were identical in all workshops (see Appendix F). The one that differed depended on the interface used, and served to evaluate its controllability. The number of respondents (boys and girls) for each workshop is given in Table 6.3.

Workshop name	Advised age	description	participants/ available slots	Code
Discover Thymio II while playing	4 to 8	Focus on discovering how a robot reacts to different inputs, what it can perceive, and what it can do.	179/180	A
Travel through space with Thymio II	6 to 9	This workshop revolved around the topic of space, which was the theme of the 2013 Festival. It focused on solving challenges with Thymio II.	108/108	B
Graphical programming with Thymio II	8 to 11	Introduction to how a robot works (sensory-motor loop) and how to use the VPL to program Thymio.	100/100	C
Introduction to programming with Thymio II	12 to 15	Introduction to robotics and the sensory-motor loop, focus on the text-based programming language through a step-by-step tutorial.	75/80	D
Advanced programming with Thymio II	14 to 18	For more experienced user. Increasingly complex challenges to achieve a more complex behaviour.	36/40	E

Table 6.2 – SUBFEST13: The five Festival workshops with Thymio II in 2013.

Workshop	Boys	Girls	% of girls
A	46	25	35%
B	34	14	29%
C	52	30	37%
D	44	15	25%
E	24	2	8%

Table 6.3 – WSSURVEY13: Number of boys and girls in the respondents of the 2013 Festival workshops survey.

The population encountered in festival workshops has a bias. First, only motivated participants come, as it is not part of an obligatory school program. Secondly, we know from SUBFEST13 that the adult visitors of the festival mostly have a higher education background, so their children are not representative of the general population.

This survey will be referred to as WSSURVEY13 in the rest of this work.

POLYTHEME13

The equal opportunities office of EPFL regularly organises series of workshops for children and teenagers on scientific topics, called Polythèmes. At the beginning of 2013, we help them set up a Polythème on Thymio II. It proposed three wednesday afternoon sessions, of 2 hours each. They consisted in different activities: the first session was a classical introduction, the second concentrated in drawing with the robot (focus on motor control and timers), and the third one had some Lego construction to build a cable car that could navigate between different levels (focus on sensor and variables). 17 children, 11 girls and 6 boys, aged 12 to 14, took part in the workshops. At the end of the three sessions some participants were very motivated and asked if they could take the robots home for a period, thus we organised a loan. After this, when we retrieved the robots, we looked at the activity logs (see Section 4.3.5) to know ho much they had used their robots at home.

This data source will be referred to as POLYTHEME13 in the rest of this work.

ETHSURVEY13: Survey during outreach program in three classes

In 2013, Dr Stéphane Magnenat, the lead developer of Aseba, conducted a series of workshops in classes to evaluate the learning of core Computer Science (CS) concepts with Thymio II and VPL. At that time with the Autonomous systems Lab of ETH Zürich, he collaborated with Dr Jiwon Shin of the Department of Computer Science, also at ETH Zürich, Professor Mordechai Ben-Ari of the Department of Science Teaching, at the Weizmann Institute of Science in Israel, and our team in Lausanne, to prepare a survey for this evaluation. This survey was reported in details in [MSR+14].

The outreach program consisted in three workshops in different schools, with short introductions to robot programming.

- A 45 minutes workshop was given to a primary school class of 10 boys and 10 girls aged 8 to 9 in Lausanne. The workshop was supervised by the school teacher and Magnenat.
- A 1.5-hour workshop was given to a group of 30 girls and 10 boys aged 10 to 15 in Zürich. This workshop was supervised by Magnenat and Shin, with six teaching assistants coaching the students closely.

- A 1.5-hour workshop was given to a teacher-training school class of 8 women and 2 men aged 22 to 30 in Liestal. The workshop was supervised by Magnenat.

All the workshops consisted in a short introduction to Thymio II and VPL, followed by a series of tasks to solve. The learning objectives were (from [MSR⁺14]):

- Understand the concepts of event, action and event-action pair. (Advanced blocks for timers and states were not taught in these workshops.)
- Understand that an event specified in an event block occurs conjunctively, when all the conditions on the sensors specified in the block occur.
- Understand that the events specified in different event-action pairs occur disjunctively, so that if more than one event occurs, all the associated actions take place concurrently.
- Create a program given a detailed description of what it should do, such as: “the robot should become red when the left button is touched.”
- Create a program given an abstract description, such as “explore a labyrinth while avoiding walls”.

Participants answered a questionnaire at the end of the workshop. The questionnaire was made of 10 questions (see Appendix G), classified into different cognitive levels, based on a mixed SOLO [BC82] and Bloom [BK56], [AKA⁺01] taxonomy presented in [MSABA13]. The final, restricted set of cognitive level included Unistructural Understanding and Applying (UU, UA), and Multistructural Understanding, Applying and Creating (MU, MA, MC) with the following definitions (from [MSR⁺14]):

- *Unistructural*: A local perspective where mainly one item or aspect is used or emphasised. Others are missing, and no significant connections are made.
- *Multistructural*: A multi-point perspective, where several relevant items or aspects are used or acknowledged, but significant connections are missing and a whole picture is not yet formed.
- *Understanding*: The ability to summarise, explain, exemplify, classify, and compare CS concepts, including programming constructs.
- *Applying*: The ability to execute programs or algorithms, to track them, and to recognise their goals.
- *Creating*: The ability to plan and produce programs or algorithms

We have to note that in the case of the primary school class, the questionnaire proved to be too difficult because text was too abundant.

This survey will be referred to as ETHSURVEY13 in the rest of this work.

6.2.3 SCHOOLDAY14: Survey during the *Day at the Heart of Science*

EPFL regularly proposes open-day events for school classes, so they can discover the different orientations available and the school's general activity. In 2014, during one such day, the *Day at the Heart of Science*, Thymio II and the activities surrounding it were presented to the visitors. We took this opportunity to have a short survey on their perception of educational robots, especially Lego Mindstorms and Thymio II. Pupils were asked to fill the form at different points during the presentation. In particular, there were questions comparing their perception of Lego Mindstorms and Thymio II.

A total of 275 children aged 10 to 14 answered the survey, 133 girls, 139 boys, 3 unspecified. This survey was prepared and analysed with Gordana Gerber and Morgane Chevalier, all questions can be found in Appendix H.

This survey will be referred to as SCHOOLDAY14 in the rest of this work.

6.2.4 UNILSTUDY14: interviews with teachers who use robots in class

Thanks to the National Centre of Competence in Research (NCCR) Robotics, we could launch in 2013 a collaboration wit the group of Farinaz Fassa, professor of Social Sciences at the University of Lausanne. With her collaborators Sabine Kradolfer and Simon Dubois, they conducted a pilot study from August 2013 to July 2014 to gather information on the acceptability and interest in robots on the teachers' part, and on the resistance or acceptance they expressed towards such devices. This work was reported in details in [kra14].

They use qualitative methods and carried semi-oriented interviews [Kau11], that followed a structured interview guide, with 15 teachers from the french-speaking part of Switzerland. This allowed the actor's subjectivity to emerge. They then undertook a discourse analysis [Bea96] to extract the different themes in the teachers' discourses and highlight shared points of view.

The informants were mainly recruited form the lists of teachers who had participated in events organised at EPFL, such as *Café Robotique* or teacher training sessions. Only one in fifteen had not taken part in those events. As a result, the population of informants shared a positive attitude towards robots. It proved difficult to find respondents who were reluctant to trying this new technology, though the interviewed teachers stated that they had faced opposition from colleagues or superiors. They would not however provide contacts of such opponents. This might be because despite their claiming, their colleagues rather showed disinterest than opposition and did not discuss the topic, because they did not want to give contacts that would result in unfavourable reports of robotics, or because the reluctant colleagues themselves did not wish to take part in the study. On the 15 teachers interviewed, there were 7 men and 8 women, teaching at different school levels: 8 in the pre-primary and primary, 2 at the secondary, 4 at the post compulsory schools, and one intervening at different levels. 8 of the respondents had been specially trained in IT support or were responsible for ICT. 11 used

Thymio II. Finally, 11 taught in public schools, 3 in private schools, and one specialised in giving robotics workshops.

The study is strongly anchored in the context of the french-speaking part of Switzerland, with the recent introduction (2011-2012) of a common school curriculum, the *Plan d'Etudes Romand* (PER). Before, each canton chose their educational policies.

We will later refer to this study as UNILSTUDY14.

6.2.5 Teacher surveys

In several occasions we gathered data from teachers, to understand their needs, motivations, or reluctance to use robots in their classes. We had many contacts with teachers from different levels and received lots of useful informal inputs, but be also had two occasions to give them questionnaires.

TEACHERSURVEY11: impressions from teachers who had taken part in the Robotics Festival

In 2011, the Robotics Festival gave a new opportunity to teachers who were interested in robotics: they could come and take part in the workshops, choose which sessions they wanted to attend, have a training session beforehand, have pedagogical materials available in advance and usable in class afterwards, and after the workshops they could get for free the equipment used provided the material value did not exceed CHF 100.

Thirty teachers took part in this program, and were asked to fill a survey. Sixteen answered. The survey has been reported in [RFBM12]. The complete list of questions can be found in Annex D.

Respondents came from different teaching backgrounds, as shown in Fig. 6.2. The survey they were asked to fill concerned primarily their satisfaction and their expectations.

This survey will be referred to as TEACHERSURVEY11 in the rest of this work.

TEACHERSURVEY14: investigating the teachers' perceptions of Thymio II

In 2013 and 2014, we prepared a survey destined to teachers in collaboration with Morgane Chevalier, who works at the HEP (teacher-training school) of Lausanne and is also a part of the Laboratory of Robotic Systems.

The goal was to analyse Thymio II along the three axes described previously in Section 2.3: utility, usability, and acceptability. Concretely, from a teacher's perspective, this means:

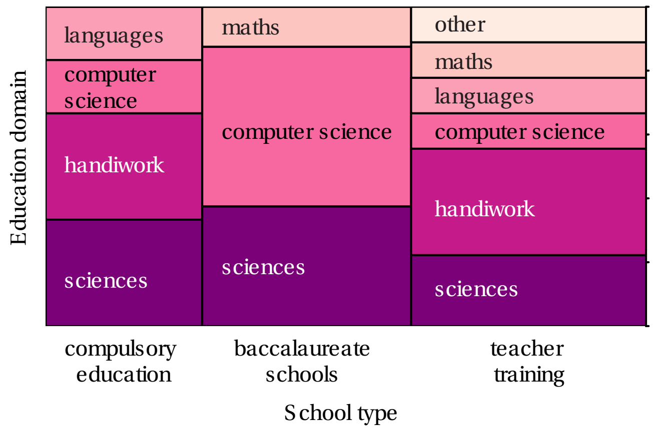


Figure 6.2 – TEACHERSURVEY11: Background of teachers who took part in the 2011 Festival (n=16, original image from [RFBM12]).

- *Utility*: Which knowledge is targeted by the teacher during a robotic activity? Do teachers feel the pupils really learn what they want them to learn? What are the benefits in using robots in a classroom?

- *Usability*: Is the robot handled easily by the pupils? Which skills are required from the teacher to use it?

- *Acceptability*: What are the constraints in using the robot in the classroom? Is the platform compatible with the practice, the resources, the objectives of teachers in their workplace?

In order to investigate these points more precisely on Thymio II, we needed to interrogate teachers who had at least some experience with it.

Our group had been organising, in collaboration with HEP, *Cafés Pédagogiques* -event where teachers would meet to discuss a topic in a more informal setting- and gradually came up with regular teacher-training sessions on robotics and technology called *Robots en Classe*. The participants to such training sessions were very interesting interlocutors for our investigations on Thymio II.

We created a questionnaire to deepen these aspects, that was sent to teachers who had taken part in the training days at EPFL. We got 25 replies, from 10 men and 15 women.

This survey's results are still being analysed, but we could already extract a few interesting points. It will be referred to as TEACHERSURVEY14 in the rest of this work.

6.2.6 CHILIEXP14: Collaboration with CHILI to use eye-tracking technology to understand the effect of the sensor visualisation

At the end of 2013 we collaborated with the CHILI (Computer-Human Interaction In Learning and Instruction) Lab to set up an eye-tracking study with Thymio II. During a student project supervised by Kshitij Sharma and realised by Lukas Hostettler, an experiment was set up to measure the impact of the sensor visualisation on the participants, through eye-tracking technology [SHL+].

In this study participants had to understand and explain how the horizontal proximity sensors worked. As they function with infrared light, they detect differently objects of different colours, that reflect various amounts of light. In the experiment, the robot would move straight towards an obstacle, and turn as soon as a certain value was measured. Depending on the colour of the obstacle, it would turn sooner (white, reflects more light) or later (black, reflects less light).

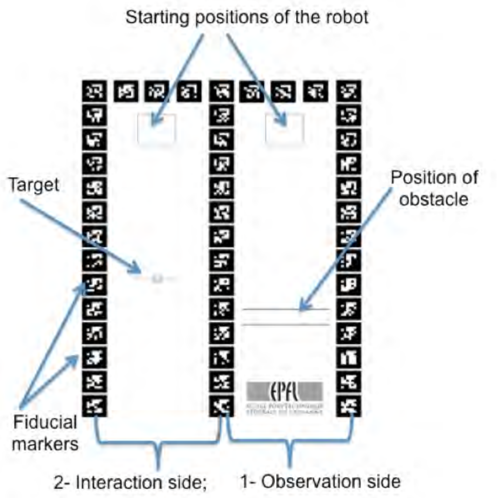
In a first phase, the participant would observe the robot with a black and a white obstacle, placed a the same distance, five times each. In the last trial of each colour, a pen was added into the pen-holder of Thymio II to mark its path. Participants then had to explain how the robot worked. In a second phase, participants had to guide the robot to a target, by placing an obstacle at the right distance. The trick resided in that the obstacle was grey, but actually reflected more IR light than the white one. They had five trials to place the obstacle correctly. They were then asked again how the robot worked. A specific playground with markers, as well as markers on the robot and on the obstacles allowed the experimenters to track the position of all objects, while the participants wore glasses with cameras to film their eyes and the playground, such as observed by them (see Fig. 6.3).

There were three different experimental conditions in the way the robot displayed sensor information. The top LED circle was used. The three conditions were:

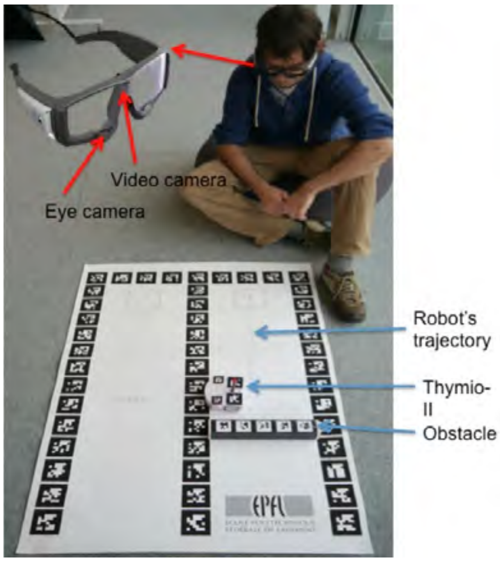
- TRUE : the number of illuminated LEDs on top of the robot is proportional to the intensity measured by the front IR sensor.
- NONE : nothing is shown on the top of the robot, the circle LEDs are off.
- RANDOM : LEDs act as if the obstacle were measured at random moments.

52 people took part in the experiment, 13 women and 39 men, with a narrow age distribution (mean 19.7, standard deviation 1.97). They were all recruited among EPFL students. There were 18 in the NONE condition, and 17 in each the TRUE and RANDOM conditions.

The answers were evaluated and classified along two dimensions, correctness (correct, incorrect) and level of abstraction (low or high). In addition, the distance to the goal for each trial of the second phase was measured. On the eye-tracking side, two measures were used, the average fixation duration on the robot, and the average fixation on the reference side.



(a) Playground used in the eye-tracking study. The observation or reference side is used to place the obstacle, while the interaction side contains the target for the second phase of the test.



(b) The whole experimental setup.

Figure 6.3 – CHILIEXP14: Thymio II eye-tracking study (images courtesy of [SHL+]).

We will later refer to this study as CHILIEXP14.

6.2.7 Final remarks on data sources

The information collected through these different experiments, events and survey created a huge amount of data that could contain relevant information. We explored many question with this data and analysed it in different occasions. The author of this thesis was involved in designing the questionnaires and analysing the data of all sources except CHILIEXP14 and UNILSTUDY14.

In the next sections we will refer to these different sources to find answers to our research questions. We will group our results by question, and refer to the data source used. We will start by looking at the motivations of the children, and their appreciation of the platform. We will move on to evaluate the actual learning outcome of these sessions with the robot, as well as the efficiency of the sensor visualisation. Then, we will examine the teacher's side of the problem to finally draw more general conclusions.

6.3 Thymio II perceived by different age and gender categories

We have explained in Chapter 2 that robots for very young children have some unique characteristics, in particular they are simplified in a way or another to avoid needing advanced skills or high dexterity to start using them. They must also meet higher security standards. This is why soldering components, assembling circuits and coding low level instructions are avoided. Instead, robots come already assembled, or in kits where the construction aspect is toy-like (Lego). The appearance of such robots is that of toys also: KIBO and CHERP use wooden blocks, the Bee-Bot has the shape of a Bee, WeDo is made of colourful Lego bricks (see Sections 2.1.3, 2.2.3 and 2.1.2). Programming languages concentrate on notions close to the children's language, and avoid written text in favour of graphical representations.

Those limitations make it harder, in our opinion, to demonstrate efficiently the sensor-actuator loop. In particular, the toy-like design of certain platforms can make them unappealing to older children or teenagers. This means that as children progress and grow, new platforms will be needed. As explained before (see Section 3.5.1), we wanted to create a robot fitting the needs of very young children while still motivating for teenagers. We also tried to avoid any strong bias on the gender. This philosophy seems contrary to what is current in the toy industry, where a precise target of age and gender is generally defined. As explained in [CSJDP09]: "Buyers need and want change as they move through life. Toy manufacturers use this to market toys for different ages of children, and also state the specific age segment on the packaging of the toy." However, our approach here is not commercial, we rather want to provide an efficient educational tool, and adapt the activity and its context to the target user.

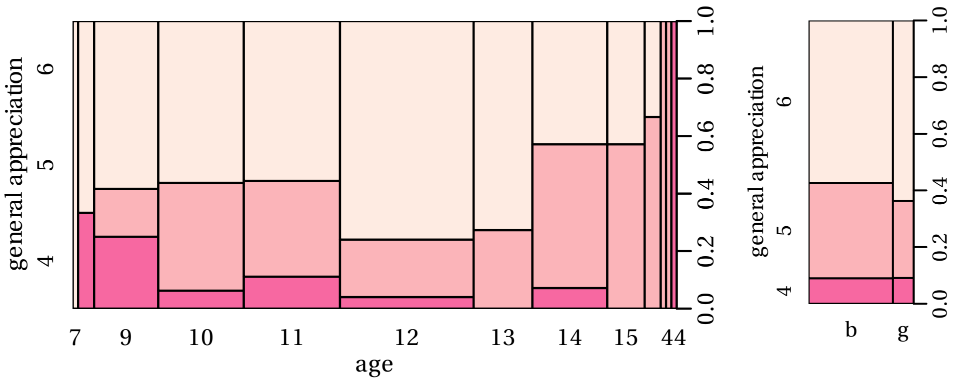
The Bee-Bot has interesting characteristics following this idea: it is purely a tool, not meant as an object of study, and is used to attain different pedagogical objectives by changing the accessories (game mats). It is however clearly limited to young children, because of its design and absence of sensors. With Lego Wedo also, the simplification for a younger age (compared to the Mindstorms) results in a limitation of the number of sensors and actuators. Most exercises propose a combination of one sensor and one motor. In addition, there is no processing unit; a computer is needed at all times to execute the program.

For Thymio II, we opted for a neutral look, that would not be too oriented toward a particular age or gender category. We gave the robot a lot of sensing capacities and interfaces adapted to different levels, allowing to progress smoothly. It is hoped that persevering with the same robot helps to gradually acquire the vision of a system.

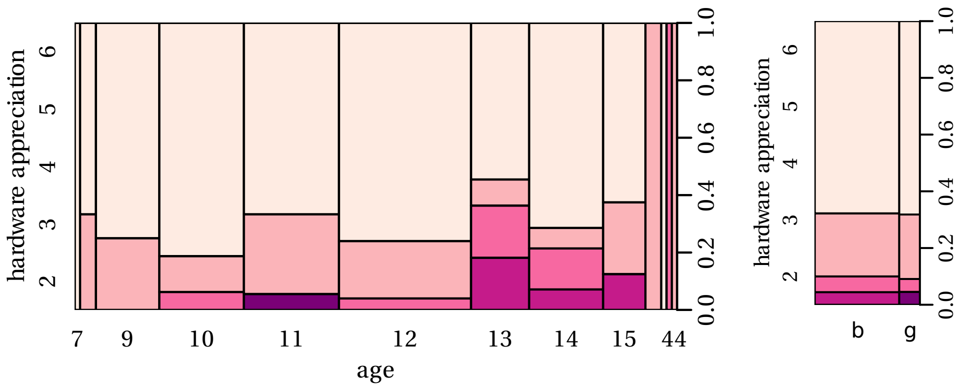
To understand this we collected data in different surveys, especially concerning the perception of the robot, the appreciation of the activities, the feeling of confidence and success they had during workshops, and their motivations in robotics.

6.3.1 Do users of all ages and both genders find Thymio II interesting and motivating?

In WSSURVEY11, we saw that the proportion of girls in the participants decreased as the age increased. In the same survey, participants were also asked about their appreciation of the workshop. We tested whether the appreciation of girls also depended on their age; but



(a) General appreciation with respect to age and gender (b=boys, g=girls).



(b) Hardware appreciation with respect to age and gender (b=boys, g=girls).

Figure 6.4 – WSSURVEY11: 2011 Festival workshop appreciation with respect to age and gender (n=116). Participants had to give a grade from 1 to 6 to different aspects of the workshop, 6 being the best grade (data published in [MRBM12]).

they was no correlation (p-value=0.48). This means that a bias against robots among girls discouraged them to subscribe, especially at an older age, but girls who gave the workshop a chance appreciated it, independently of their age.

Overall, the general appreciation of the workshop in 2011, as well as the appreciation of the hardware (the Thymio II robot) were very high (see Fig. 6.4). General appreciation correlated neither with age (p-value=0.44) nor with gender (p-value=0.63); the hardware appreciation did not correlate with gender either (p-value=0.97), but it did correlate with age (p-value=0.03). The robot was less appreciated by older children. Participants were also asked to characterise the workshop with the words *educational*, *funny*, or *interesting*. The general appreciation correlated strongly with the *interesting* qualification. We noticed that young children loved the LEDs, but older ones might have found Thymio II too plain.

It seemed with these results that we would need to address the expectations of the different age groups more carefully. We thought that by adapting the materials and context of the activities, we could meet with their expectation.

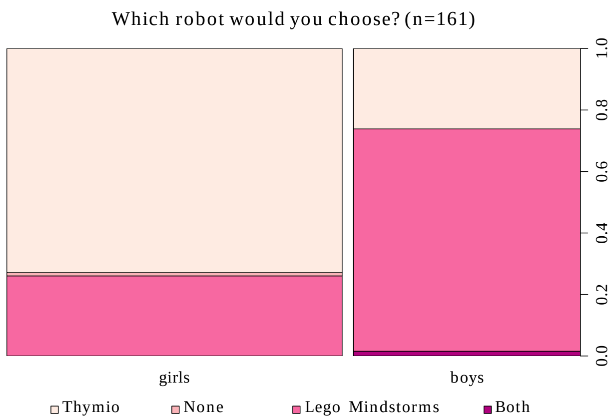
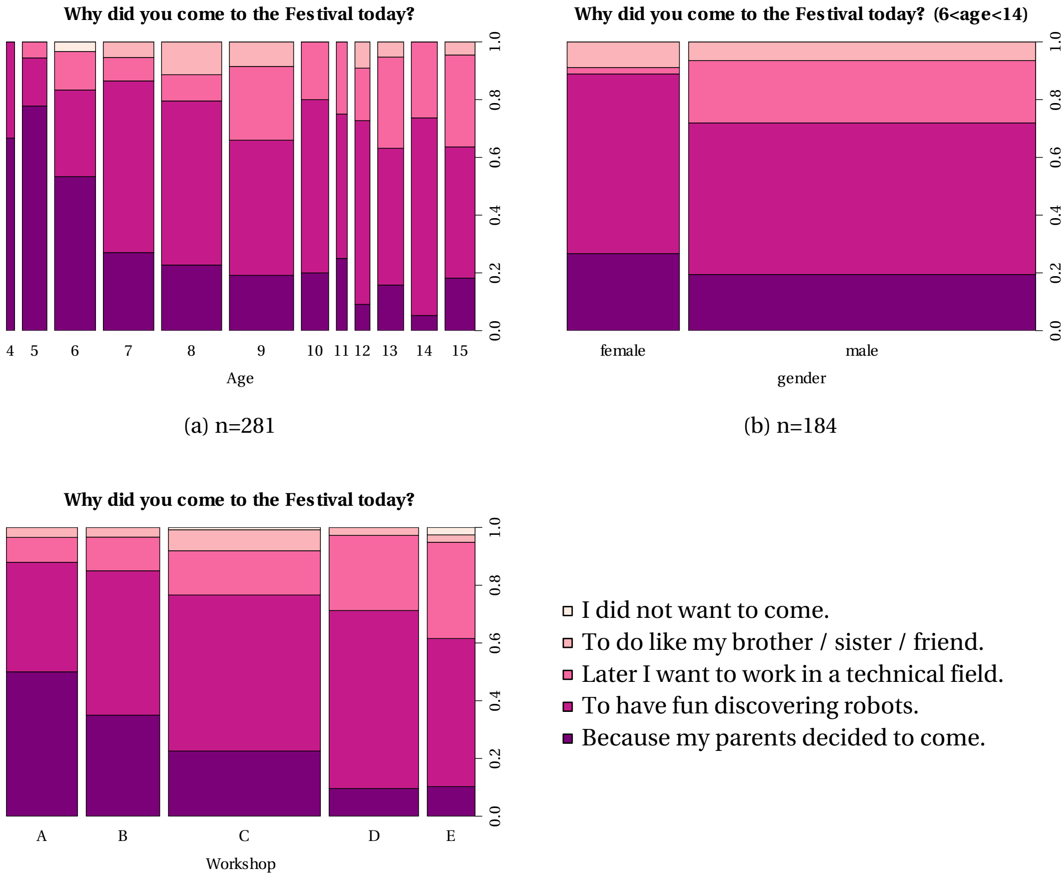


Figure 6.5 – SCHOOLDAY14: Children's choice between Thymio II and Lego Mindstorms.

We were satisfied to note that Thymio II's design was, as we had hoped, *a priori* gender-neutral. This might come from its general aspect, which is that of a white, finished product, with all technical aspects hidden at first sight. Indeed, it was suggested by Vikas Gupta, CEO of Play-i, that *girls were uninterested in the robot when it had visible wheels and wires* [Sch14]. We tried to verify this in our SCHOOLDAY14 survey. At the beginning of a presentation about robots and Thymio II, pupils were asked to choose which robot they would like to have, between the Lego Mindstorms and the Thymio II, presented in pictures. This was before the presentation of the robot, in order to gather answers based on the first impression; the Mindstorms had apparent cables and mechanical parts, while Thymio II was simple with just LEDs on. The form was filled with a pencil, so some answers might have been modified later in the presentation, so we did not take into account sheets with signs of erased or modified answers. The result is shown in Fig. 6.5. Indeed girls prefer the appearance of Thymio II (76% of girls choose Thymio II). Boys however prefer the looks of Lego Mindstorms (67% of boys). The choice of the robot correlates strongly with the gender (p-value$<10^{-7}$, considering only answers from children who said they did not know any of the robots before). It seems that while boys appreciate Thymio II workshops and like the hardware used (as seen in Fig. 6.4), the design of Thymio II is not as appealing as other, more technical-looking robots.

In conclusion, to the question *Do users of all ages and both gender find Thymio II interesting and motivating?*, we can answer that most participants appreciated the robot and the workshop, and found it interesting. However, in this very positive feedback, we can find nuance. The look of Thymio II seems to appeal more to girls than to boys who, given the choice, would pick the more technical-looking Lego Mindstorms. Older participants also were less motivated by the hardware.

With these considerations, we need to try and better understand the expectations of different groups, and keep in mind to have a strategy to adapt the Thymio II activities to the target group.



(a) n=281 (b) n=184 (c) n=281

Figure 6.6 – WSSURVEY13: The motivation to visit the Festival with respect to age, gender, and workshop respectively (data published in [RCMM13]). In the gender comparison, we limited the sample to age groups where both boys and girls were present, as the motivation also correlates with age.

6.3.2 In what measure are the different age and gender groups' expectations different, and can Thymio II address them?

In WSSURVEY13, we investigated the visitors' motivations and expectations. We wanted to better understand their goal in attending the Festival, what they expected from a workshop, and how this varied with age and gender. This time Thymio II was used in different contexts with the different age groups, hopefully providing high satisfaction to all participants.

First, we asked them why they had come to the festival, and what was their primary goal in attending. We observed that the motivation to come to the festival varies with age and with the gender (see Fig. 6.6).

As previously published in [RCMM13]:

> To the question *Why did you come to the festival today?*, most respondents replied *to have fun discovering robots*. However, among the younger ones (3-6), *because my parents decided to come* is prominent, while the older ones give importance to *because later I want to work in a technical field*, as illustrated in Fig. 6.6a. We see that young children are brought by the motivation of their parents, and as they grow older they start to see an interest of the event for their future career. This difference is reflected in the workshop proportions (see Fig. 6.6c). This motivation is also different between girls and boys: girls show nearly no interest in working in a technical field later (see Fig. 6.6b). Instead, their main motivation is to have fun and discover robots, followed by the fact that their parents brought them. This effect is observed even if we remove the respondents older than 14, where there are nearly no girls.
>
> When asked about their primary goal in coming to the festival, the respondents mention mostly *to learn new things* and *to have fun*. On this question there is no difference in the answers of boys and girls, and a correlation with the age is not clear either. However, we saw that people with different goals chose different workshops (Fig. 6.7). Workshop A, having the word *play* in its title, attracted indeed more children who wanted to *have fun*, while the two workshops based on text programming (D and E) attracted a majority of children who wanted to *learn*.

Do Thymio II and its activities meet these expectations? When participants were asked if their primary goal had been met (to *learn new things* and to *play* as seen above), 85 % replied very much, 14 % a little and less than 1 % said not at all. This answer did not correlate with age, gender or workshop type. This first feedback was extremely positive.

> We then asked participants what they had appreciated about the activities they took part in. We treated this by workshop (see Fig. 6.8), since the contents were different, but keeping in mind that workshop types correlate with age. We see that in workshop A , mostly the fact that they could *play* was appreciated with a little bit of *instructions and challenges were stimulating*. Workshops B and C were also appreciated quite a bit for the fact that participants could *play*, but much less than in A. The importance of the *challenges* stays at a similar level but *I learnt things that will be useful later* becomes as important as the play. The importance of *learning* is also there for workshops D and E, but the *play* loses importance while the *stimulating challenges* become primordial, especially for E. There is no hint that the gender impacts the appreciation. We start to see that the things that were appreciated are linked to the things that motivated them to come and to their goals, which explains their very high satisfaction. Because Thymio II's design is neutral, adapting the activities renders possible the acceptance of the same hardware by a wide age range.

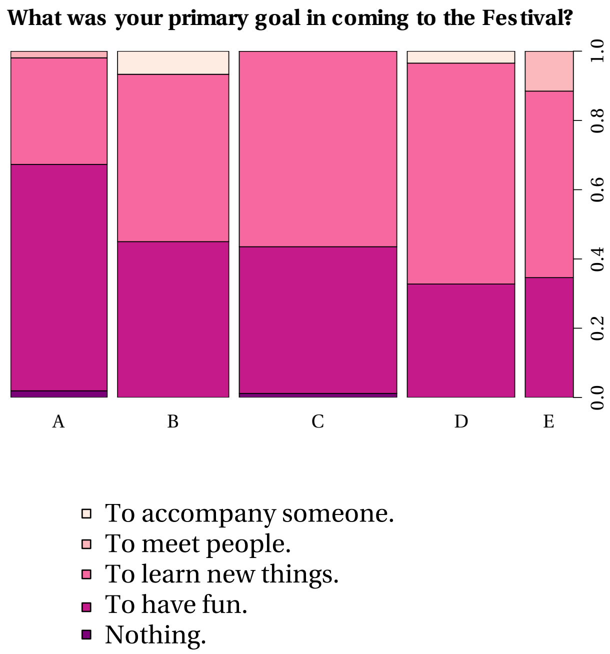


Figure 6.7 – WSSURVEY2013: Primary goal of the Festival visitors, by workshop (n=281, data published in [RCMM13]).

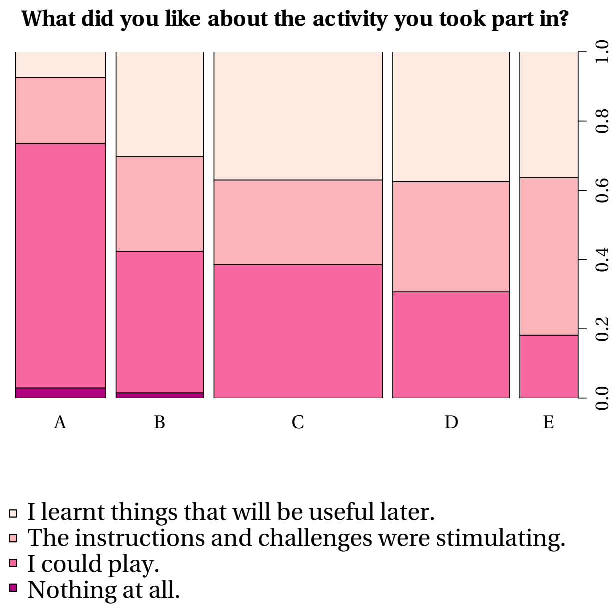


Figure 6.8 – WSSURVEY13: Aspects the visitors appreciated (n=393, data published in [RCMM13]).

In conclusion, we saw that the expectations towards robotic activities change with respect to the different age and gender groups. Young children, girls and boys alike, mostly want to play and are satisfied when they can. With older ones, we start to see the importance of learning useful things and to be challenged by the activities. The most important difference we could note between boys and girls is that girls generally do not consider technical careers, while for boys it is a motivation to attend events like the Festival. In order to address these different needs, we proposed workshops with the same hardware but with different activities. We observed that indeed children with different interests picked different workshops.

6.3.3 Are the interfaces adequate?

As different interfaces were used in different workshops with different age groups, we also asked some questions to help us understand how those interfaces were perceived by the users. We wanted to know what was the perceived controllability of those interfaces, thus we asked a question that was dependant on the workshop. The questions were:

- *Is it easy to know which button to press, for example so that Thymio II follows a track?* for A and B
- *Is it easy to know which cards to use, for example so that Thymio II stops moving when you hit it?* for C
- *Is it easy to know which keywords to use, for example so that Thymio II stops moving at the edge of the table?* for D and E.

The answers to this question are shown in Fig. 6.9

> We see that in the case of A, B and C there are more than 50% of *very easy*. The button interface and cards of the VPL seem easily understood. The scripting language seems to be perceived as more complex. In workshops D and E most participants find it moderately easy to understand which keywords to use.

When asking about their success in the tasks, a majority answered they very much succeeded (see Fig. 6.10a). The success is lower for workshop D and especially E, which uses the Aseba script language, perceived as less controllable also. When asked whether the activity was too difficult, it was again workshops D an E that stood out, with the activities seen as *a little too difficult* (see Fig. 6.10b). However we can relate this with the appreciation (see Fig. 6.8) where for workshop E, the *challenges* were mostly appreciated. This perceived complexity of the Aseba scripting language is not necessarily a problem but rather a proof of its richness. And indeed, Laurent Michel, the teacher in charge of workshop E, stated that the students felt they had not had *enough time* to solve all the challenges, and took the list with them to continue at home. We can conclude that the complexity of Aseba and Thymio II does not need to be

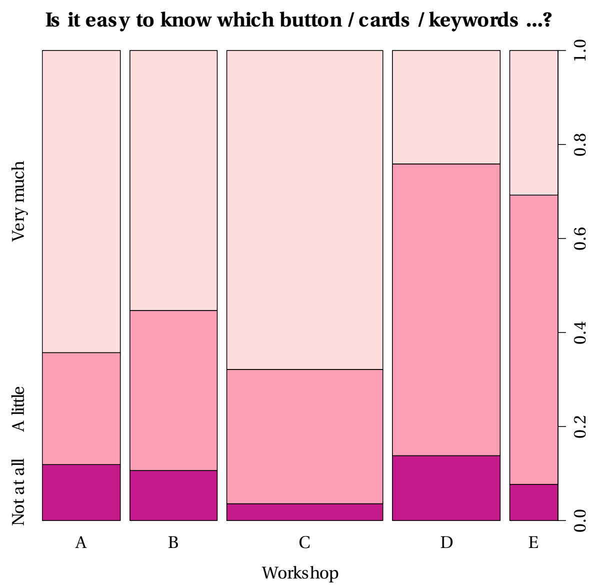


Figure 6.9 – WSSURVEY13: Perceived controllability of the different interfaces for Thymio II: the buttons and VPL are seen as quite understandable, while the script language is more challenging (n=257, data published in [RCMM13]).

reduced, and the tasks given were adequate, but more time could be provided for a better satisfaction.

This confirms that the interfaces were adequate for the different age groups, providing good controllability. The most complex interface was, as expected, Aseba Studio with the scripting language. Satisfaction is high anyways because though the script language is more difficult to grasp in a short workshop, older participants liked being challenged and wanted to learn.

6.4 What do Children actually learn?

We wondered then, how well the participants really acquired knowledge. Being satisfied or having fun does not imply having learnt anything knew. In several occasions, with pre- and post-tests we collected data about how well certain concepts were understood. All the concepts we tested were related to the sensor-actuator loop or to computer science. The computer science questions focus more on the programming environment.

6.4.1 How well do children manage to understand such concepts as variables, or events?

In 2011, the WSSURVEY11 was conducted to evaluate the children's learning with Thymio II and Aseba Studio. This focused on the Aseba script language, as the VPL had not yet been released. At the end of the questionnaire, six questions tested CS and robotics concepts such as

(a) Participant's feeling of success in the workshops (n=248).

(b) Participant's sense of difficulty of the workshops' tasks (n=252).

Figure 6.10 – WSSURVEY13: Participant's feeling of success and difficulty: overall the activities are perceived as quite easy (data published in [RCMM13]).

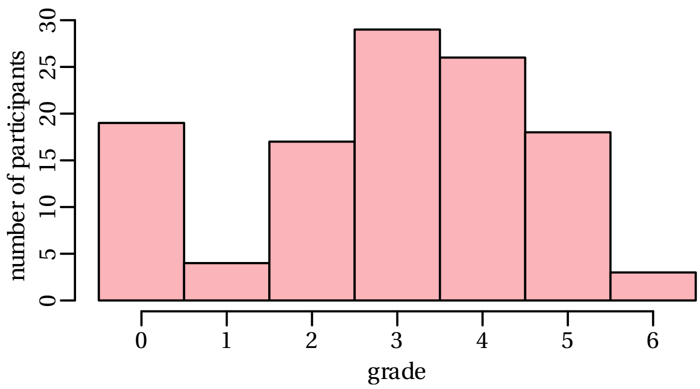


Figure 6.11 – WSSURVEY11: Grades obtained by children at the final test in the 2011 workshops (n=116). The best grade is 6, when all 6 questions have been answered correctly (data published in [MRBM12]).

the sensor-actuator loop, sensors, variables, or condition statements. A grade was computed by adding a point for each question answered correctly. The histogram of the grades is given in Fig. 6.11, the peak at 0 is explained by the fact that 17 respondents did not answer these questions. The grade correlates with age (p-value=0.02). During the workshop we noticed that older children generally progressed faster in the tutorial than younger ones, thus it seems they are able to grasp these concepts faster, and they might have acquired more experience during the session. The grade also correlated with gender (p-value=0.02) with girls obtaining worse grades than boys. This is not surprising since the distribution of girls and boys were not equivalent: there were nearly only young girls, while there were both younger and older boys. Thus, the grades of both groups were influenced by their ages.

The answers to these questions (see Fig. 6.12) showed that participants had not really understood what was a robot (*What is a robot exactly?*), and they did not really grasp the concept of

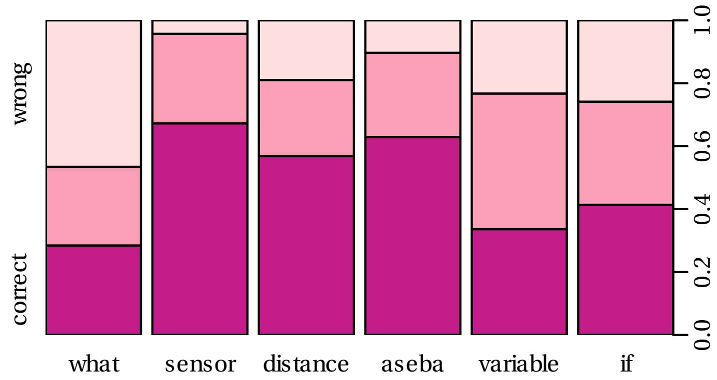


Figure 6.12 – WSSURVEY11: Answers to the different knowledge questions at the 2011 Festival workshops (n=116). The medium pink area in the middle represents invalid answers, while the light and dark pink areas show wrong and correct answers respectively (data published in [MRBM12]). **what**: What is a robot exactly? **sensor**: What are the characteristics of a sensor? **distance**: At which distance can Thymio II detect obstacles? **aseba**: How does Aseba allow to program a robot? **variable**: What is a variable? **if**: What is an if?

the sensor-actuator loop. The concept of sensor, however, was well understood, both in the general concept (*What are the characteristics of a sensor?*) and its application to Thymio II's sensors (*At which distance can Thymio II detect obstacles?*). They also understood how Aseba allows to program Thymio II (*How does Aseba allow to program a robot?*). The technical aspects of programming (*What is a variable? What is an if?*) were not so well understood.

These impressions came from a first experience, and we saw that probably the sessions were too short and the important concepts not explained enough for participants to really acquire them.

In 2012, in WSSURVEY12, we asked similar questions. The tutorial had been adapted, and made longer. At the end of the workshop, the answers to the different questions were good (see Fig. 6.13), though a relatively large group (35 on 163) did not know how far the sensors could detect. The most problematic point was the understanding of the `if` statement. While a majority (69 out of 163) answered correctly, 29 users stated that the English language was a problem, and 37 that they did not know the answer. This question (*What is an if?*) seems a problem for younger participants in particular (see Fig. 6.14).

In short, children managed to understand well what sensors were and what was the role of the computer in robot programming, but had more problems with precise Aseba instructions, and the definition of a robot. These results highlighted the fact that the English language could be a barrier to understanding the text-based programming language for children.

In parallel, VPL had been developed to free the programming from constraints like language, use of a keyboard, and the ability to read. With this, we could differentiate the tools for different ages.

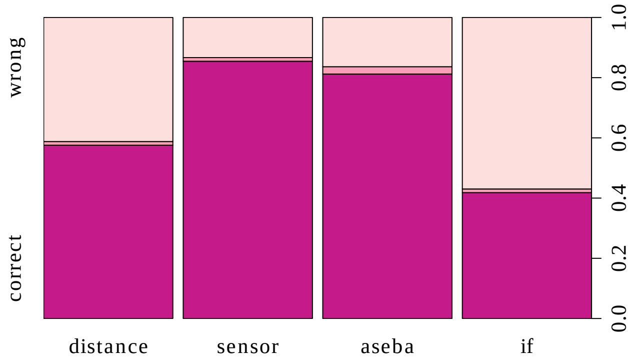


Figure 6.13 – WSSURVEY12: Answers to the different knowledge questions at the 2012 Festival workshops (n=165). The medium pink area in the middle represents invalid answers, while the light and dark pink areas show wrong and correct answers respectively. **distance**: How far can Thymio detect objects? **sensor**: What are sensors for? **aseba**: How does Aseba allow to program the robot? **if**: What is an if?

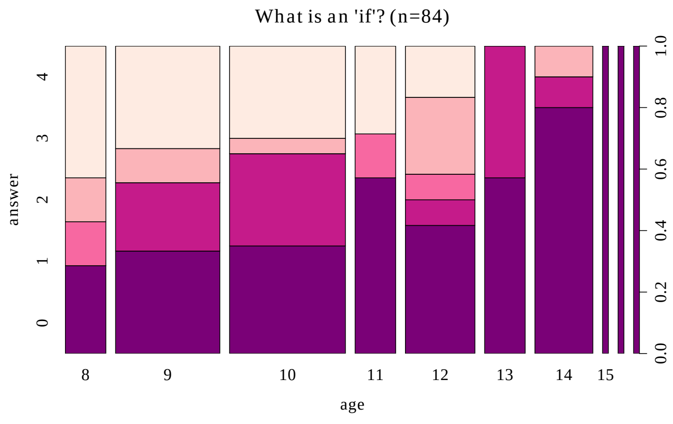
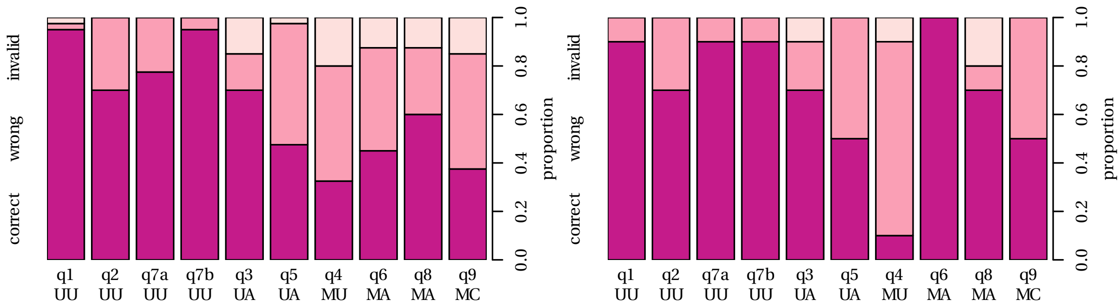


Figure 6.14 – WSSURVEY12: The answer to *What is an 'if'?* with respect to the age. **0**: A keyword telling the robot to take a decision depending on the value of a variable. **1**: An English word that I do not understand; I would prefer Aseba in French. **2**: A keyword allowing to store a value into a variable. **3**: A keyword allowing to execute several times a piece of code. **4**: I do not know / I did not understand.



(a) Answers from the Zürich workshop, n=40

(b) Answers from the Liestal workshop, n=10

Figure 6.15 – ETHSURVEY13: The answers of students in the questionnaire on the understanding of VPL (data published in [MSR+14]). The code for the cognitive levels translates to: first letter: **U**nistructural/**M**ultistructural, second letter: **U**nderstanding/**A**pplying/**C**reating (for definitions see Section 6.2.2)

6.4.2 Can users quickly grasp core CS concepts in VPL?

Once a first version of VPL had been released and tested with a few classes to make sure there were no major issues, we could test whether it was adapted to teach Computer Science (CS) concepts.

Thanks to ETHSURVEY13, we could understand more precisely which CS concepts could be acquired during a short session using VPL. Fig. 6.15 shows the results to the questionnaires distributed in the workshops of Zürich (6.15a, 10-15 years old) and of Liestal (6.15b, 22-30 years old). The questions are classified by cognitive level (two dimensions: Unistructural-Multistructural, and Understanding-Applying-Creating, for definitions see Section 6.2.2), with the question number also available. For all the questions, see Appendix G.

In both cases we can see that the UU level is quite well acquired. UU in this context means understanding and explaining a single block, or a single event-action pair.

We also observe that question 4 (MU) was the most problematic in both cases, though not targeting the highest cognitive level. This question targeted the fact that two identical event-action pairs produce a compilation error. While when working on the robot, this would be signalled by the programming interface and one would need to correct it before running the program, this rule was not explicitly stated during the session. This means that they might not have encountered this situation, or not realised the rule, but rather eliminated the faulty pair when signalled.

Question 5 (UA) generated a mixed response. After investigating, we realised this question highlighted a problem with the understanding of the ground sensor block. The colour displayed on the sensor icon (red in the case something was detected, green in the case nothing was detected) was not clear for students. In this case a short workshop was not sufficient to attain the UA level.

The MA questions (especially question 6) seemed better understood by the older Liestal students. Those questions required to predict the outcome of a program made of several event-action pairs. It would be interesting to investigate this further to evaluated whether the age really influences the results or if it is simply due to the better linguistic capacities of adults towards complex statements in questions.

Finally question 9 (MC) which had the highest cognitive level, had mixed results. This shows that even though the workshops were quite short in time, some participants could already grasp more advanced concepts and had the capacity to choose the right block to attain their goals.

These results give us good reasons to think that with VPL, users can very quickly become independent and start designing their own programs. We saw that most students understood the concepts of event-action pair, and the fact that events happen asynchronously and concurrently. Roughly half of them attained higher cognitive levels. It would now be interesting to do a similar evaluation with an adapted questionnaire for younger pupils.

6.5 Is the sensor visualisation efficient?

The previous evaluation concerned mostly the computer-based programming interfaces. However we also implemented behaviours that illustrate different concepts of robotics without even the use of a computer. One of the features we mostly wanted to assess was the sensor activity visualisation through LEDs on the robot's body.

6.5.1 Does the sensor visualisation really help pupils in grasping the functioning of the sensor?

In WSSURVEY12, we found an occasion to test the influence of the sensor visualisation. Two groups did the same workshop in parallel, one with the sensor visualisation activated, the other with the visualisation deactivated. At the end of the workshop, participants were asked questions about the sensors.

In Fig. 6.16, we show the participant's answers with respect to the presence of sensor visualisation. The answers are very similar in both groups, there is no correlation between the presence of the sensor visualisation and the answers to the questions (p-value=0.43 for the distance question, p-value=0.78 for the sensor question).

This data shows no influence of the sensor visualisation in the understanding of the sensors. The context of the workshop was probably too directed for the participants to discover anything by themselves. They all did the same tasks, following the tutorial. The tutorial used in the workshop explicitly stated that one could watch the sensor values in the programming interface, but it did not mention anything about the LEDs. There was no need for them to use this feature, and no situation in which using it would especially help.

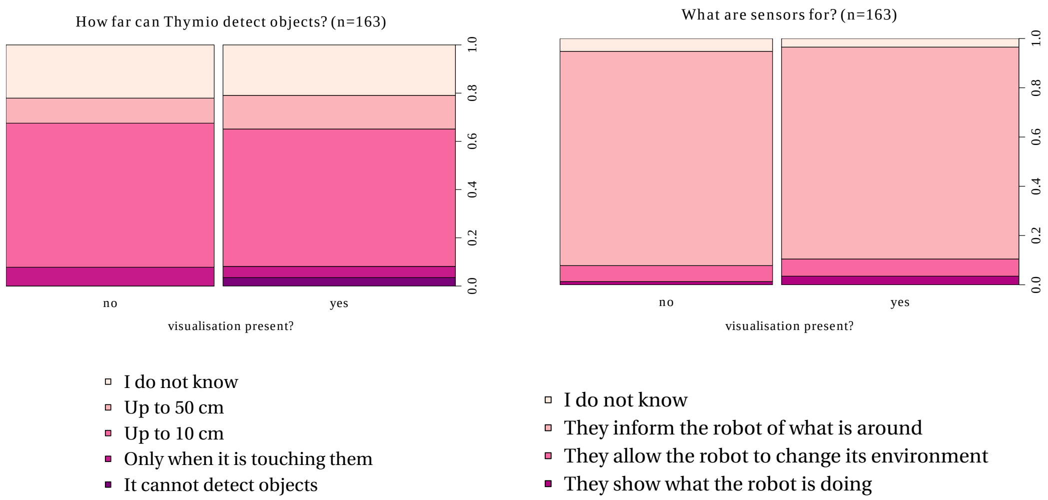


Figure 6.16 – WSSURVEY12: Answers to the workshop survey with respect to the visualisation of the sensors.

6.5.2 Is this visualisation used consciously when planning a behaviour for the robot?

Though from what we could measure in WSSURVEY12, the visualisation did help in understanding the characteristics of the sensors, we wondered if people noticed it, or used it consciously.

As explained before, to collect data for WSSURVEY12, we had two series of robots. In one room the robots had the sensor visualisation, in the other not. In the middle of the day, the robots were swapped. Participants could not experience both conditions, but assistants in the workshop, who were not informed about the robot swap, did notice the change. In the group that had the visualisation in the morning, but not in the afternoon, one assistant asked if something had changed, saying "I thought there was something happening when you approached the sensors" and another thought he had deactivated the function by mistake. In the other group, one assistant stated "I had not noticed these LEDs lighting up next to the sensors, it's actually convenient!" and two others nearby agreed.

After this, The CHILI Lab gave us the opportunity to investigate a bit the effect of this visualisation [SHL$^+$]. During the CHILIEXP14 experiment, people had to solve a task involving the horizontal proximity sensors by placing an obstacle at the right position to make the robot reach a target, and explain how the sensors work. Three types of visualisation were tested with the top sensors: TRUE, with LED activity proportional to the value measured by the sensor, RANDOM, with unreliable display on the LEDs, and NONE, with all LEDs inactive.

After the experiment, it appeared that the visualisation condition did not correlate either with the correctness or abstraction level of the explanation of the robot's functioning. In addition, no anticipation pattern could be found in the eye-tracking data. They measured however that the LED activity attracted attention, indeed the average fixation duration on the robot during the first observation phase was significantly longer in the TRUE and RANDOM conditions. In the second phase, the first improvement was significantly worse in the TRUE condition than in RANDOM and NONE. They also measured that in the interaction phase, participants look significantly more on the reference side in NONE and RANDOM conditions than in TRUE condition.

The sensor visualisation indeed attracts attention, but the final result was not improved by this. There is a plausible explanation to these results: participants in the TRUE condition might have had higher confidence in the robot's functioning than the others. Thus the ones with NONE and RANDOM condition would start experimenting earlier, having no certainty of how the robot works, while the ones in TRUE condition would be disturbed by the reaction to the grey obstacle. This is supported by the fact that participants in the TRUE condition looked less at the reference side, because of their belief of knowing how the robot works.

These experiments showed us that the sensor visualisation did not bring any immediate benefits to the understanding of how sensors worked, nor to the solving of a task involving sensors. We could however verify that the LED activity attracted attention and that people noticed it. The effect of a feedback might not be as trivial as we thought, and it would be interesting to study the conditions in which feedback might bring benefits, and when it might prevent constructive reflective process.

6.6 How is Thymio II used once at home?

With the first Thymio, we had come to realise that it was merely a support for the workshop activity and not a reusable polyvalent tool, though children built an emotional attachment to it (see Section 3.3). In the design of Thymio II, we made efforts to come up with a robot that could sustain interest for a longer period. In this section we will present some elements to understand whether our design goal was met.

6.6.1 Analysis of the forum

An analysis of the forum activity gives us hints on how Thymio II is used. Indeed, it is the primary contact point for users who encounter problems or have questions. Forum activity spans from 2012 to 2014 (analysis based on the state of the forum on december 13th, 2014). Out of 124 different users who wrote a post about Thymio II and Aseba (members of our team excluded), 27 returned and posted on different topics or over longer periods, the others mostly come for a single question. 11 helped other users by answering their questions, and 6 contributed with their own tricks and examples, or by offering translations and editing the wiki. 19 users explicitly stated that they used Thymio II to teach (in school, after school clubs and even at university). Out of them 8 are recurring participants, and 4 contributed by helping others or providing translations. It is interesting to note that two users mentioned their age to ask for forgiveness if they had made a mistake (one was 60 and the other nearing 80). Apart from Thymio II users, there are also 15 people who take part in the forum activity but use other platforms with Aseba.

The topics of the messages can be sorted into different categories. This way it is possible to distinguish between messages that rather denote problems at the first use, and messages concerning more advanced questions that show a more in-depth use.

- First we have *customer service questions*: these concern software installation, and defects of the robots. This kind of questions will rather happen when people receive the robots or the first time they use it, because most defects until this day are not due to wear, but rather to unreliable components (defect USB cables, motor or H-bridge, battery not plugged, deep discharge because the robot was not recharged upon reception and such).
- We have a certain number of *firmware upgrade questions*, those are due to the fact that when firmware v3 was released, we made a call to owners to upgrade the firmware. This does not give much information about their usage of Thymio II.
- Then we have *questions concerning the code or Thymio II*, generally because users do not understand how to do a certain thing or want more detail on a precise point. In this case, we know they are doing something by themselves, trying to develop a project or idea. Questions in this category concern principally Aseba code, with a few on construction, physical characteristics of Thymio II, and VPL.
- There are *demands and suggestions*, generally people asking whether there is compatibility with other platforms or softwares, and wishes for future robots or versions of the software. This denotes interest for Thymio II but not necessarily its usage. It can be that people want to know whether the platform suits their needs or that they see a limitation.
- There are *contributions*, meaning spontaneous gift of material, tips or information to improve the website and the platform, including software bug reports. Users have to be somewhat invested in Thymio II and make a regular use of it to do such things.
- There are some *specific demands from teachers* who want to know who is doing what, advice for classes, information on competitions etc.
- Finally, there are some users of Aseba who are not using Thymio II, and write about *other platforms* (e-pucks, Aseba Challenge, Aseba Playground).

The number of posts for each type of question is given in Table 6.4

We see that the forums were not active in the first year, and seem to have stable input in 2013 and 2014. Messages denoting rather first use or hesitation before going for the platform

Year	Customer service	Firmware	Code and usage	Demands	Contributions	Teaching	Other platforms
2012	8	3	12	-	4	-	5
2013	21	2	27	13	6	4	19
2014	26	-	27	10	8	3	5
Total	55	5	66	23	18	7	29

Table 6.4 – Main topics discussed in the forums (until December 2014).

(customer service and demands, 78 posts) are slightly fewer than messages denoting more in-depth use (code and usage questions, contributions, teaching, 91 posts). Overall, the number of users in the forum is small compared to the number of Thymio II sold (124 users for more than 8'000 units distributed). Forum users seem more focused on text-based programming. In addition, teachers tend to be recurring users and to contribute in some way.

Based on the forums, the use of Thymio II at home seems limited, with just a few troubleshooting questions arising, indicating only short-term use. Posts showing longer-term use are mostly related to programming, showing that people who use the platform at home concentrate on this aspect rather than on construction or interaction with the basic modes.

6.6.2 Are the robots used after a workshop?

During the POLYTHEME13 courses, pupils had the occasion to learn how to use Thymio II during three sessions. After that, they were very motivated, and several of them asked if they could borrow one Thymio II to use it at home. We let them borrow robots from the last day of the workshop for around two months. Thanks to the logging capacity of the robot, when they gave the robots back, we could see whether they had used it once at home. We obtained data from seven robots (see Fig. 6.17).

From the logs collected, we see that only four out of the seven participants actually used their robot once at home. For the three others, as there are no records between the last workshop day and the return date, it means that the robot was not even turned on. In the four robots that were used (rob2, rob3, rob4 and rob7 in the graph), rob3 and rob7 were used less than five minutes, only in pre-programmed modes. Rob2 was used once for five minutes in pre-programmed modes, and once for 32 minutes, including 24 minutes of programming, and 8 minutes of pre-programmed modes. Rob4 was the most used, with 6 different instances of use, including three that were less than 10 minutes of pre-programmed modes. It was also used three times for programming, in sessions of 74, 7, and 45 minutes.

From this data it seems that the use at home is rather reduced, some children do not even touch the robots though they were motivated and borrowed one. When they do use it, the sessions are short if using the pre-programmed modes, and apparently longer when programming.

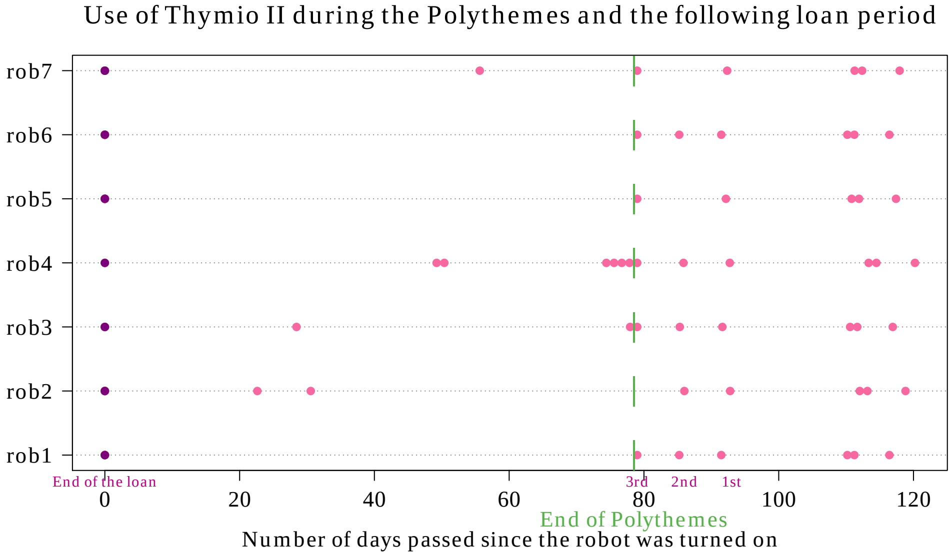


Figure 6.17 – POLYTHEME13: Use of Thymio II by children during a workshop and at home. The black dots on the left show the moment when the robots were given back and the logs are retrieved. The red line indicates the beginning of the loan. The three sessions of the Polythèmes are also visible, and on the far right, lab activity (firmware upgrade, battery charge, tests). The dots are not aligned because of the rounding errors when counting the days.

Once again, long-term use is related to programming. We can suppose this extends to other users of Thymio II as well.

6.7 Is Thymio II adopted by the schools?

In the previous section, we mentioned that teachers took part in the forum and showed interest for our platform at different teaching levels. We also know that several schools in Switzerland placed orders with Mobsya for series of Thymio II (more than 900 units were sold to schools). Some teachers contacted us for direct collaboration. Our collaborator Morgane Chevalier went to do sessions in several primary school classes. We also had several instances of Thymio II being a platform in high school: with Laurent Michel for the optional course on computer science, with Grégoire Aellig for the end-of-studies work (Travail de Maturité, TM) his students had to submit. Another initiative for a TM based on Thymio II came from a student herself, Mariane Brodier, who used the robot to do light paintings. A collaboration with the International School of Geneva to develop pedagogical material is ongoing, and since 2014 teacher training courses were set up in collaboration with the pedagogical school of Lausanne. In France, the National Institute for Research in Computer Science and Automation in Bordeaux (INRIA) developed pedagogical materials for schools based on Thymio II.

The teachers who actually used Thymio II in class however, are, from what we could gather when talking to them, mostly passionate themselves about robotics, and took the initiative to introduce them into their curriculum. This led us to wonder how teachers actually perceived Thymio II, and robotics in general. We wanted to understand what were their motivations when deciding to use robots, and how this could impact educational robot design. We had several occasions to investigate this. In this section, we will share our findings and conclusions on this topic.

6.7.1 What benefits do teachers find in robots?

Starting from the model proposed by [TPSC+03] (already explained in Section 2.3), we first take a look at the robot's utility in class. Utility encompasses the actual efficiency of the robot as a pedagogical tool, but also, from the teacher's point of view, the perceived benefits and the disciplines that can be taught.

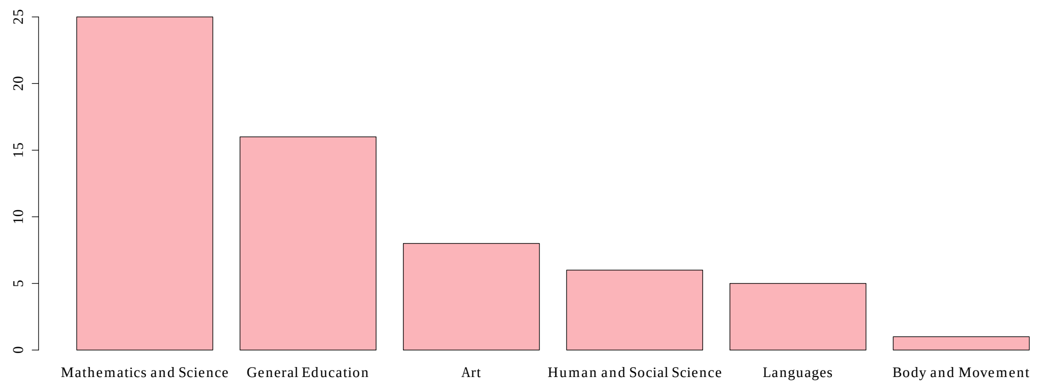
UNILSTUDY14 brings up several interesting aspects of the benefits perceived by teachers when using robots [kra14].

First, the robots disrupt the classical school order. It allows children to apply the knowledge they have seen in theoretical form. The robots moves in front of them, instead of them just using written text as a source of knowledge. They have to change their point of view.

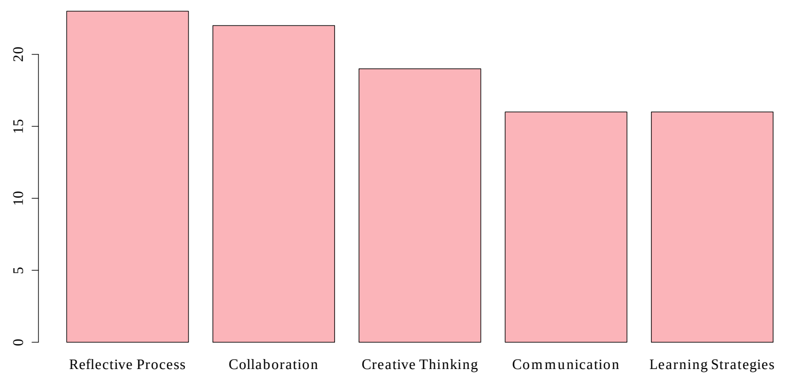
This is considered an advantage especially for children who face difficulties with the standard teaching styles. It also promotes a "group spirit" that helps pupils who are not integrated, and gives them a chance to have a better experience.

In TEACHERSURVEY14, we questioned 25 teachers who had some experience with Thymio II about their motivation to use it in class and the benefits they perceived. First, 23 of the 25 respondents agreed with the statement *According to you, Thymio II allows pupils to learn*. The two who disagreed explained their answer by the young age of their pupils, and the fact that many other devices were available. When probed about the domains in which Thymio II would be adapted, all agreed on *Mathematics and Science*, followed by *General Education* (16 agreeing). All other proposed domains received less than one third of agreements (see Fig. 6.18a). Teachers saw more potential for the transversal objectives of the learning plan, 23 agreeing on the *Reflective Process* and 22 on the *Collaboration*, but the other objectives all received at least 16 agreements (see Fig. 6.18b). In addition, 22 agreed with the statement *According to you, Thymio II encourages the pupils' engagement in the school activities*, and 23 say they would use Thymio II if they had some available.

Thanks to this study we conclude that teachers who are acquainted with Thymio II find it useful, especially to teach *Mathematics and Science*, but also to foster transversal skills like *Reflective Process* and *Collaboration*. They think using a robot would motivate pupils. This study included teachers working at different levels of education, from primary school to high school, but still most found a usefulness to Thymio II.



(a) Domains of the Swiss curriculum (PER)



(b) Transversal objectives of the Swiss curriculum (PER)

Figure 6.18 – TEACHERSURVEY14: Teachers' opinion on the disciplines in which Thymio II is best suited (n=25).

6.7.2 Is Thymio II usable in class?

Teacher perceive a utility for Thymio II, but what of its usability? Is the robot handled easily by the pupils? Which skills are required from the teacher to use it? We saw in Section 6.3 that young users liked the design of Thymio II, had a feeling of success during the activities and a quite good feeling of controllability over the basic behaviours and VPL. Obstacles in the usability of the text programming were in part due to the keywords perceived as complex, and to the fact that the interface was in English.

TEACHERSURVEY14 gave us insight into how the teachers perceived its usability. First, we asked teachers if in their opinion an expertise was required either in computer science or in robotics to use Thymio II in class. In Fig. 6.19a, we see that opinions are a bit divided on whether technical skills are required from teachers to use Thymio II.

We then asked them to evaluate how easily Thymio II itself could be handled by pupils in their opinion. With all three questions teachers were very confident that the pupils could manipulate Thymio II (see Fig. 6.19b).

In suggestions on what could be improved to handle Thymio II more easily, one person mentioned additional functions to control the robot's wheels in position, and one asked for more precise sensors for science class.

Overall, it seems that teachers consider the robot usable by the pupils, but seem a bit unsure whether they need more skills to use it themselves. This confirms informal discussions we had with teachers and supports the need for teacher training sessions.

6.7.3 What use do teachers make of Thymio II?

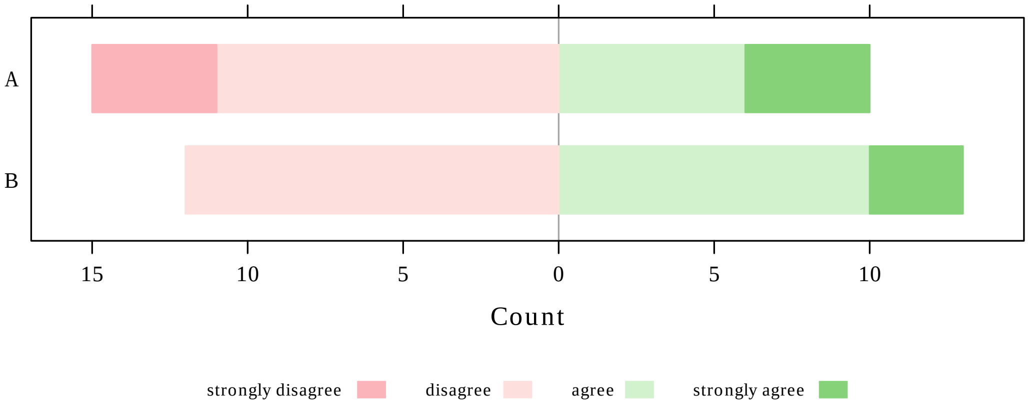
Until now we have considered mostly teachers' perceptions of Thymio II's utility and usability. Now we take a look at the actual use of the platform.

In UNILSTUDY14 it became obvious that different robots were used in different contexts and with different age groups.

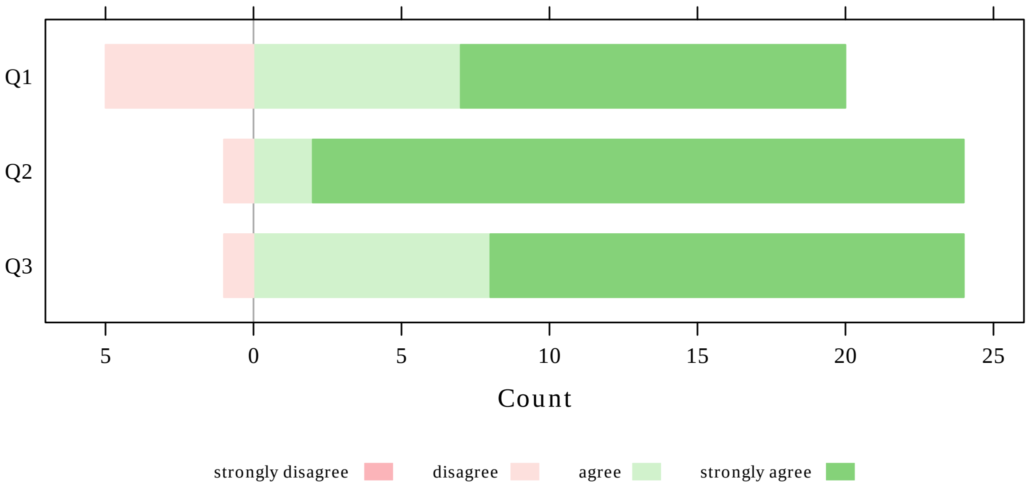
With children aged 4 to 10, teachers often used the Bee-Bot first to give an introduction, and then use Thymio II. In this case robots were used as tools to teach different topics, such as spatial awareness and German in one case, and bring a different approach. They also saw Thymio II as a good introduction to robotics.

In senior high schools, robots were used in dedicated courses as object of study or examples of application of disciplines related to robotics (computer science, STEM, electronics). Thymio II was used before or in parallel with Arduino and Lego Mindstorms.

In between there seemed to be a gap. The reason for this stems from the Swiss school curriculum. In primary school, one teacher teaches all topics and chooses a pedagogy; in high



(a) According to you, to use Thymio II in class you need skills in **A** Robotics **B** Computer Science.



(b) **Q1**: According to you, Thymio II is easily handled by children. **Q2**: According to you, it is easy to understand how to turn Thymio II on or off. **Q3**: According to you, it is easy to understand how to activate Thymio II's different modes (pre-programmed behaviours).

Figure 6.19 – TEACHERSURVEY14: Teachers' opinion on the usability of Thymio II.

schools there are specialised courses on computer science and physics; but in secondary school different teacher teach different topics, and “there is not much room for robots”.

6.7.4 What are the obstacles to the adoption of robots by teachers?

We saw that teachers are quite convinced by the utility and the usability of the robot, though we interviewed mostly people who were favourable to robots in the first place, but still hesitate to actually use them. The penetration of Thymio II is still somewhat limited, especially at certain levels like compulsory secondary school. What makes the robot acceptable in primary and high schools, but not in secondary? We investigated this topic to understand whether there were obstacles in the acceptability of Thymio II in schools.

During the interview of UNILSTUDY14, Prof. Fassa’s group could identify crucial factors for the adoption of robots in classes.

First, money is often stated as the problem. The PER (Swiss French curriculum) does not explicitly mention robots, thus they are seen as optional. Lego Mindstorms being quite expensive, schools are reluctant to invest in the material. Private school teachers do not meet this obstacle, as budgets are bigger.

The school structure can create obstacles, because it is sometimes not very flexible and adaptable to new ideas. For example, ordering robots can become problematic, as stated by a teacher from canton Vaud: materials should be bought from the CADEV (Centrale d’Achats de l’Etat de Vaud) and Thymio II was not listed there yet. In compulsory secondary school, the separation of topics leave less space to integrate robots in interdisciplinary activities.

Teachers who want to use robots have to be strong willed and invest time, take special training, convince their direction to invest in the materials, order them, fit the activity with the curriculum. As a result, current users are actually pioneers, because of the lack of institutional injunction.

In TEACHERSURVEY11, we had had the occasion to question such pioneers about their use and intentions of use of robots. They were personally motivated, having volunteered to help with the workshops in the hope of discovering new platforms and gaining some pedagogical material. But despite their interest, they mostly did not use yet the robots seen at the Festival (Bee-Bot, Thymio II, Lego Mindstorms, Boe-Bot, WeDo) in their class (see P2 on Fig. 6.20). They stated being proactive and looking for new materials, confirming their position as pioneers (P1). They were convinced that the Festival experience was a good training (P3) and confirm that having ready-to-use pedagogical materials at the end of the workshop is important (P5 and P6). They seemed convinced they would use what they learnt in class (P9). This shows us that even pioneers, who are very interested and proactive, do not use robots in class. Their appreciation of the ready-to-use materials and their conviction that on day at the festival was a good training opportunity hints that training and materials are lacking.

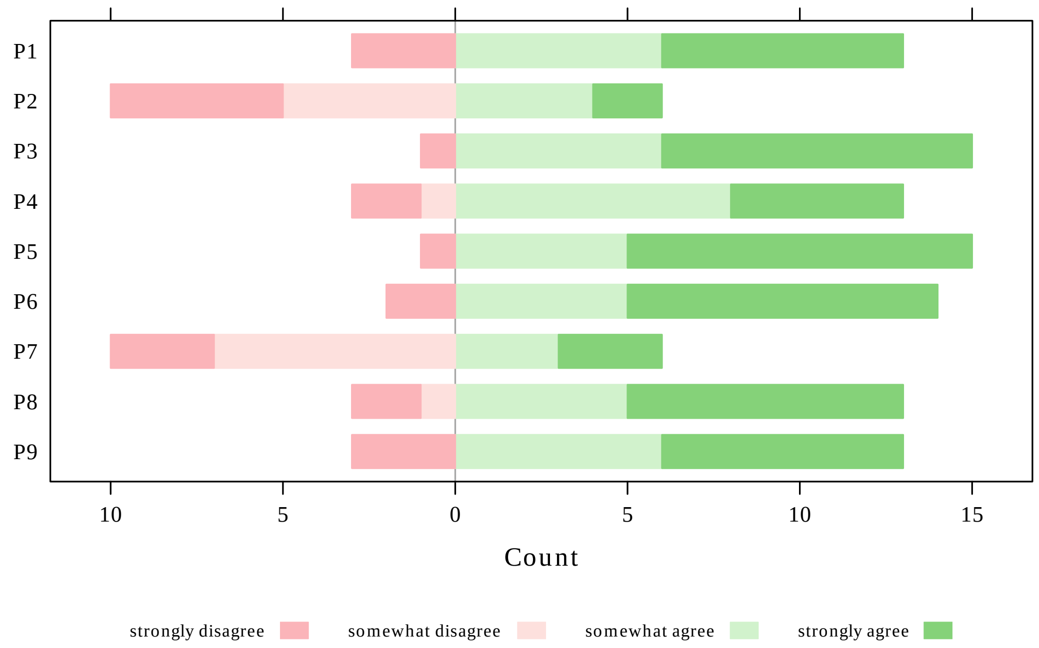


Figure 6.20 – TEACHERSURVEY11: Teacher's answers to the 2011 survey (image from [RFBM12]). **P1**: I am always looking for new technologies for my teaching activity / promotion of sciences. **P2**: I already use the type of educational tools seen at the festival. **P3**: The participation to the workshops is an excellent training opportunity. **P4**: I appreciated to be able to check the use of the presented tools. **P5**: It is important to receive the material (robot, kit) at the end of the workshop. **P6**: It is important to be able to use the material in my class. **P7**: I was able to visit the others activities of the festival, such as shows and exhibitions. **P8**: I will for sure use what I learned in my activity. **P9**: I am motivated to develop new educational documents/activities to use these technologies in my classes.

Finally, in TEACHERSURVEY14, open questions confirm the same problems. As the PER does not explicitly mention the robots, many feel they are not really acceptable because they do not fit the curriculum or the traditional way of teaching. One person mentioned that the programming was good in high school, but not earlier for compulsory secondary school, because programming was too abstract and complex, and the pre-programmed behaviours were too limited. One mentioned they needed to take some time to find how to fit it with disciplines like french or maths. One said they could not use Thymio II within the prescribed framework, because they had to reconsider their way of teaching.

In conclusion the identified obstacles are mostly due to the school program not mentioning robots, making it difficult to integrate them in the lessons, justify the expense, and finding appropriate materials and training. Teachers who use robots are pioneers, others might not feel confident enough to take this step.

As of now, Thymio II has started to gather interest in Swiss schools, where teachers who are curious about robots see it as a as valid as the Bee-Bot or Lego robots, and in France, where the INRIA has started developing appropriate curricula. We can expect that as the official school programs evolve to include programming or more technology, Thymio II will be considered as a valid option.

6.8 Discussion

In this chapter, we have evaluated many different aspects surrounding Thymio II.

First, we could verify that children of a wide age range appreciate Thymio II and find it motivating, though the visual appearance of the robot seems to please rather young children and girls. With appropriate interfaces and activities, users of all ages can be satisfied with their experience. We saw that young children are motivated by playing, and follow their parent's advice in deciding to take part in an activity, while teenagers are more motivated to learn, either by curiosity (girls) or because of their career interests (boys). The robot and its interface were appreciated by all, and considered quite controllable. The Aseba script language, which gives much wider programming possibilities, is perceived as more complex and thus is only suited for older children.

Then, we could measure that some key concepts were apprehended successfully by participants to introduction sessions. Sensors were generally well understood, as well as the roles of Aseba, the computer, and the robot in the process of programming. In VPL, even in short sessions, participants had no problems with the concepts of event-action pairs. Problems came more when considering especially the ground sensor block, other blocks being well understood, or when having to predict compilation errors.

We evaluated the sensor visualisation, and while we saw it attracted attention, we found no reason to think it influenced the understanding of how a sensor worked. Rather, in the eye-tracking experiment, it might have led to over-confidence from the participants.

With Thymio II in homes, we had a first impression of it not being used often, but with time we started to see more activity on the forum. The forum seemed to attract especially people interested in programming, and contributors. Teachers seemed to appreciate the social aspects provided by the forum, and some became recurrent users.

Finally, we concentrated on teachers, and we realised that Thymio II is still in a pioneers phase, concentrated rather in two groups: in primary schools with the basic behaviours, and in high schools, for specific programming courses. Identified blockages encompass the lack of training, of ready-to-use materials, and of institutional injunction. The framework of the public education also limits the possibilities, because of budget constraints, administrative rules (such as ordering through CADEV), or because of directives to fit a curriculum which does not mention robots. Private schools seem to experience more flexibility in that respect. Otherwise teachers considered Thymio II useful especially for mathematics and science, and transversal skills, and usable by the pupils. The acceptability was the most limited, with many teachers thinking it did not fit into the curriculum or into the standard pedagogy.

This, however, could be changing soon, as programming is progressively inserted into the standard curricula, as in Italy [Md14], Estonia [Gar14], France [AFP14], and even the German speaking part of Switzerland [hc14]. In the next and final chapter, we will give a synthesised view of this work, before proposing some interesting leads for the future.

7 Synthesis and Outlook

Technology is nowadays omnipresent in our lives. In this context, robots have often been proposed as educational tools, with various roles, such as that of teacher, peer, learning tool, or object of study. The expected benefits are enhancing the pupils' motivation, making their learning easier, encouraging transversal skills such as collaboration, creativity or thinking skills, and finally educating pupils on technology, both because this field is currently missing from education and to encourage people into technical careers.

However, many questions are left open, and the efficiency of such tools has not yet been assessed. Most of the articles published on the topic are descriptive in nature. Those that report results with a complete experimental design are almost only centred on the Lego products. The dynamics of the relationship between pupils, teachers, and robots are not yet well understood.

Thanks to the Swiss National Centre of Competence in Research Robotics (NCCR Robotics), we had the opportunity to design, deploy and evaluate one such educational robotic platform. We opted for a small wheeled robot that would take the role of a tool or of an object of study. We named it Thymio II. It was developed based on our previous experience with Thymio and the e-puck robot. We aimed to provide a rich programming experience, by having a large set of sensors, an intuitive development environment, and the ability to concentrate on high-level instructions. In addition, we wanted the robot to be usable directly out of the box with pre-programmed behaviours, and to allow for construction and creativity thanks to a sober white look combined with various attachment means on the robot's body.

Thymio II has distance, capacitive touch, temperature, acceleration, sound and infrared communication sensors, two wheels, a loudspeaker, and 39 LEDs spread over its body. It is completely open-source and open-hardware, and has a community website containing all information as well as a forum for users. It was created with the production stage in mind, and could be produced thanks to the Mobsya nonprofit association. We implemented a non-conventional model to transfer the design of the robot to the industry. The whole design was released under a Creative Commons license, allowing to reduce costs for the producer, ensuring that everybody could still acess the information, and giving the academic side a chance to gather data from a high number of robots. This situation has been mutually beneficial and appreciated by the users. For example, the public schools in Geneva decided to adopt only open-source and free software, which made Thymio II very interesting for them.

On the software side, we decided to use the Aseba framework that follows an event-based approach. Aseba's lightweight virtual machine could run on a microcontroller and allowed for reprogramming one's own behaviour without losing the basic software or risking to damage the hardware because of faulty instructions. Finally the robot had six pre-programmed behaviours demonstrating its different possibilities, and could be programmed either with a Visual Programming Language (VPL) or with the Aseba script language. Moreover, a special sensor activity visualisation through LEDs was implemented throughout the three user interfaces.

To this day, more than 8'000 units of Thymio II have been produced and sold, including more than 900 that went to schools. On several occasions, we could gather data to evaluate its potential as an educational robot, especially during workshops for children like those of the EPFL Robotics Festival, but also through collaborations with other institutions. For this first evaluation phase, we concentrated on teaching notions that are fundamentals to robotics and to have a first understanding of many technological devices : the sensor-actuator loop, and programming in particular. We tried to encompass in our analysis not only the software and the hardware aspects, but also the users, namely the pupils and the teachers.

We could first assess that Thymio II's design and concept was appreciated by a wide age range, and both boys and girls. We noted that the motivations in attending robot workshops varied with age: young children mostly wanted to play and followed the impulses of their parents, while with older ones practical considerations took over, such as wanting to learn something useful for their careers. We saw that boys' and girls' motivations start to differ with age. Thus, making introductions to technology at a very young age is essential in order to reach out to girls. We showed that while Thymio II's design was especially appreciated by young children and girls, it was possible to adapt the activity and materials surrounding it to create a motivating experience for all age and gender groups. Finally, we measured that users had a good sense of success and controllability with the different activities and interfaces, the Aseba script language being perceived as more difficult by the corresponding age category.

We proceeded to measure the learning outcome of the workshops. In the text-based programming workshops, we saw that pupils understood well the concept of sensors and what happened between the robot, the computer and Aseba Studio. However, precise instruction such as the `if` statement, and the use of variables were not well understood. The definition of a robot and the sensor-actuator loop also remained problematic. In VPL, we saw that the concepts of events and event-action pairs were quickly grasped even in short sessions. We could gather information and improve some problematic blocks. We saw that understanding that several event-action pairs could happen concurrently was not a problem, but predicting the outcome of a program was more difficult.

We also evaluated the concept of visualisation of internal activity through the LEDs. While we assessed that this feature attracted attention, we could not show that it was exploited consciously by the users, nor did we note any influence on the sensor understanding. In the eye-tracking experience, it seemed even linked to a worse performance at the test, possibly showing that it gave users over confidence in the system.

We found some information on the home use of our platform through the analysis of the forum and of the activity logs recorded on the robots themselves. It seems that many people have a first experience with the robot and then stop. In the forum, this results in troubleshooting questions and single-visit users. In the activity logs, we saw that five out of seven users who were motivated and borrowed a Thymio II, did not use it or used it just for a few minutes. People who spent more time on Thymio II and became recurring users of the robot focused on the programming. We saw nearly no instances of people exploiting Thymio II's construction possibilities. We could note also that teachers seemed to appreciate the forums for its social aspect, and invested time to learn programming.

Finally we tried to understand better the attitude of teachers towards robotics and observe Thymio II's penetration in schools. We started with an overview of their expectations in using robots: they see it as a way to break the classical school order and bringing additional motivation, especially from pupils who otherwise had difficulty. They see its application more in the field of Mathematics and Science, a bit for the General Education, but they also see its use rather for transversal objectives like Reflective Process and Collaboration. Overall they found Thymio II usable by their pupils, but were unsure whether they would themselves need to be skilled in Computer Science or Robotics in order to use it. The actual use of Thymio II seems separated in two groups: in primary schools (for first introductions to robotics, exploring spatial awareness, occasional activities) and in high schools (for courses on computer science, or end of studies project). The obstacles to introduce robots in classes that were identified were often institutional in nature. As the Swiss French school program does not explicitly mention robots, their introduction must be justified in some way. Budget constraints arise, as well as administrative issues such as not being able to order them through the official catalogue. The second problem was the lack of training and ready-to-use pedagogical materials. We did not find teachers who were particularly against the use of robots. Those who decide to use robots are for the moment passionate pioneers, who will invest time and sometimes their own money because of a personal interest, and develop their own materials. It seems important now to develop more examples, materials, and training possibilities, so that teachers do not need to become experts of the field, but can grasp quickly the tool's possibilities and decide whether to include it or not in their pedagogy.

Overall, in this thesis we saw that we could bring some concepts to improve the design of an affordable, flexible educational mobile robot, with adapted interfaces for different groups of users. This was successfully implemented in workshops and participants acquired new knowledge on technical topics. We identified weaknesses in Thymio II's use by people at home and in schools, where there seems to be a need for people to be more accompanied. Teaching materials, exercises and examples would be a good way to move on.

7.1 Contributions to the state of the art

We can summarise the major contributions of this work:

- We have successfully combined a set of design principles into an open-source and open-hardware robotic tool that is robust, reliable, and adapted to children
- Thanks to the open philosophy, we could easily transfer the developed platform to an external entity responsible for its production, creating a profitable situation for both parties
- We have shown the sustainability of this collaborative model between research and industry with more than 8'000 units distributed to date and an ongoing production
- This widely spread platform can then serve as a basis for studies in the domain
- We have proposed a design that is appealing to girls
- We have shown that a rich, complex hardware is not necessarily inaccessible for younger pupils
- We have shown that it is possible to use the same platform with very young children and teenagers alike to provide a meaningful and accessible experience, by using a common technology and adapting the activities and materials
- We have identified differences in the needs and motivations of children with respect to their age and gender
- We have taken teachers into account in our evaluation, and shown that they are motivated but need more institutional injunction, teaching materials, and training opportunities

Contrary to our first Thymio project, on Thymio II we did not directly identify any major problem in its specifications. Thymio II and Aseba seem to be good tools to learn programming and robotics, and now it would be interesting to evaluate their potential in other domains, especially transversal skills, on which teachers have high hopes. To proceed and continue to analyse the different aspects of robots in education, we need to move beyond the first literacy phase, where teachers are only pioneers and users do not get past the first introduction sessions. To achieve this, we believe that there is a need for more materials, both for learners and for teachers, and that they need to be accompanied as the field is still new. In the next section, we will give leads for the future developments of the Thymio II project.

7.2 Guidelines for the design of educational robots

Based on our experience, we can list a set of design guidelines for educational robots, that proved to be successful in our case:

- A neutral look (not toy-like, not too technical) makes the robot acceptable for a wider range (in gender and age) of users.
- Varying the surrounding material and activities then provides to the specific needs of the different age and gender groups.
- Keeping rich sensing and actuating capacities is important to learn programming, and is not per se an obstacle for young children.
- A platform intended to be deployed among young children needs to fit security requirements, such as the CE toy certification. This limits the electronic construction possibilities, and to a lesser extent, the mechanical construction possibilities.
- Young children need specific programming interfaces: they should be graphical (to get rid of reading or language problems) and high-level (closer to the child's language than to the technical language).
- Teachers should not need to be experts in the field in order to use robots in classes; adequate material must be provided.

7.3 Next steps for the Thymio II project

On the technical aspect of Thymio II, efforts are now already oriented towards Augmented Reality, that will be integrated into Aseba Studio and VPL. It will give users more possibilities to inspect their programs. This will reinforce the debugging capacities that were lacking in VPL and are necessary for an efficient trial-and-error process. A prototype interface was already tested in [MBAKSed]. In parallel, efforts will be invested to port Aseba onto tablets, so that pupils can really follow their robot, observe it through the tablet as it interacts with its environment (see Fig. 7.1). This also means that Thymio II will need RF or Bluetooth communication; a CTI project will start soon to work on those aspects.

Now that we know that Thymio II is acceptable for pupils of different ages and genders, and allows to teach notions of programming and robotics, it would be interesting to study the dynamics of group work on robots, and verify whether there are any benefits in terms of collaboration. The motivational effect of robotics should also be assessed on the longer term, and with children who experience difficulty otherwise. We also observed that users who stated being interested in Thymio II would borrow one, and then not even turn it on once at home. This raises questions about the motivation and dynamics of autonomous home learning. It would be interesting to compare this situation with the behaviour of people using e-learning methods.

Figure 7.1 – Augmented Reality will give users more tools to understand robotics (visual by Maria Beltran).

Finally, as the community is starting to grow, the website is being transformed for better visibility of the contents, so that new users know where to start. In general, both private users and teachers alike need to be accompanied and more materials will be developed. The INRIA Bordeaux already created a curriculum using Thymio II, and other teaching sequences are under development in collaboration with the International School of Geneva. In addition, regular *Robots en Classes* sessions will both train teachers and allow to keep contact with them. With more and more materials and trainings sessions available, and the progressive introduction of more technology in the curricula, it will be possible to evaluate more precisely the effect of the presence of robots in schools.

A Procès-verbal entretien Basile GASS – 14 juillet 2010 - par Nathalie Nyffeler

Basile Gass est professeur de math, physique, informatique et un des responsables robotiques au collège Léon Michaud à Yverdon. Il enseigne au 7e et 9e année des 3 niveaux. Il s'intéresse de près à la robotique et à la programmation. Il va organiser la coupe de robotique au sein de son collège pour la première fois en février 2011.

Réaction positive suite à la présentation de Thymio. Voici une liste des fonctions imaginées lors de notre discussion :

- Capteurs audio (clap des mains pour le contrôler)
- Lumière => lampe de poche à roulettes
- Détecteurs pour éviter que Thymio tombe de la table
- Pouvoir enregistrer sa voix
- Crochet arrière pour accrocher des véhicules (type Duplo par exemple)
- Fonctionnement sans pile (côté développement durable), prévoir un accu avec un chargeur sur une base rigolote en forme d'animal ou de personnage ludique
- Détecteur de couleur qui peut dire la couleur d'une plaque de lego par exemple
- Détecteur de champ électro magnétique
- Format en une pièce mais avec compatibilité plaques lego ET duplo (prévoir par exemple un velcro pour faciliter le collage)
- Eviter de devoir aider l'enfant pour manipuler Thymio dans la mesure du possible
- Boussole
- Enregistre le tracé d'un parcours effectué puis on appuie sur un bouton et Thymio reproduit le tracé de lui-même

- Ajouter des bras ou pinces qui seraient vendues en plus
- Wi / Boîtier qui permettrait de télécommander très facilement le robot (en forme de volant)
- Faire un tracé avec du scotch par terre, mettre le robot dessus et il suit le scotch (le scotch doit pouvoir être ôté facilement et sans marque)
- Développer un soft de programmation très ludique pour les enfants de 6 à 10 ans sur la base de dessin (formes géographiques, barre, ligne, etc) avec ou sans table graphique. L'enfant peut ensuite prévoir un tracé sur le programme et Thymio le reproduit
- Basile pense que l'intérêt premier du robot est d'avoir un robot très simple et sobre (en une pièce) et que c'est le soft qui fera la différence
- On pose le robot dans la chambre de l'enfant, le robot est ensuite capable de retracer la chambre de l'enfant (en 2D). L'enfant a ensuite le plan de sa chambre et peut s'il le souhaite changer les couleurs et les meubles d'emplacement sur le logiciel et ensuite imprimer (les filles adoreraient sûrement l'option)
- Le robot peut mesurer et calculer des distances et des aires
- Aider l'enfant à comprendre le principe des unités
- Option « tamagochi » avec plaque interactive pour nourrir, soigner, divertir Thymio

Basile pense que le robot pourrait être intéressant au Gymnase du type : « kit je monte mon robot moi-même » à la condition sine qua non qu'il n'ait pas de soudure à faire. Si c'est le cas, alors il pense que des enfants dès 12/13 ans pourraient le faire avec de l'aide.

Prix psychologique maximum : CHF 100.—avec logiciel ne lui semble pas trop élevé

Format

- Ne pas prévoir l'option « démontage », un seul bloc
- Look actuel : TB pour M. Gass
- Par contre prévoir des kits « customization »
  - Transformer mon robot en avion, camion de pompier, voiture de course, animal familier qui peut bien évidemment faire le son de l'animal
  - Prix par kit : environ CHF 20.—
  - Attention : importance de pouvoir installer un petit bonhomme dans les kits (Playmobil, Lego technics, Duplo, Little People,...)

B Mandat HEIG-VD

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IDENTIFICATION ET ANALYSE DES FREINS ET MOTIVATIONS DANS L'UTILISATION DU ROBOT MODULAIRE THYMIO AUPRES DES ENFANTS DE 6 A 13 ANS AFIN DE VALIDER LE MEILLEUR SCENARIO DE DEVELOPPEMENT POUR LA GENERATION 2 DE THYMIO

Madame Riedo, Monsieur Mondada,

Suite à nos divers entretiens de juillet et août 2010, j'ai le plaisir de vous adresser la présente formalisation de l'étude de marché prospective réalisée pour le laboratoire LSRO de l'EPFL :

1 CONTEXTE GENERAL

Le mandant est le Laboratoire de Systèmes Robotiques (LSRO) qui fait partie de l'Institut de Microtechnique à l'EPFL. Dans ce cadre le groupe mobots (Miniature Mobile Robots) a été créé et développe diverses activités pour la promotion de la technologie et de la robotique, par exemple en organisant des présentations et des activités pour les classes.

En 2008, le groupe s'est impliqué dans l'organisation du premier Festival robotique (http://festivalrobotique.epfl.ch/).regroupant plusieurs évènements. Un des ateliers « bricole ton robot » a permis à près de 140 enfants de bricoler un robot sur la base d'un premier kit de robot modulaire.

Ce premier prototype est né du workshop sur la robotique réalisé avec des élèves et des enseignants de l'ECAL ainsi que des ingénieurs EPFL. Le premier concept était basé sur M. Patate. Pour le robot M. Patate, un set d'accessoires (roues, capteurs) devait permettre de transformer n'importe quoi en robot.

Figure 1: *Premier prototype ECAL / EPFL*

Le premier kit a été développé sur la base de ce concept. Une dizaine de kits prototypes ont servi lors du premier Festival de robotique. Comme le nombre de kits était limité il fallait à la fin de chaque atelier démonter les bricolages et récupérer les kits pour le groupe suivant. Ce kit nécessitait une aide des assistants pour le monter correctement ; les câbles amovibles sans détrompeurs amenaient des erreurs de câblage et donc de comportement. L'électronique nue (donc facilement court-circuitable) ne correspondait pas aux normes de sécurité strictes des jouets permettant de le distribuer).

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Le premier kit était constitué de 5 parties en PCB nu : deux roues avec moteurs, un module avec trois capteurs IR, un module avec des boutons, un module avec batteries. La forme du PCB permettait de planter les modules dans le bricolage.

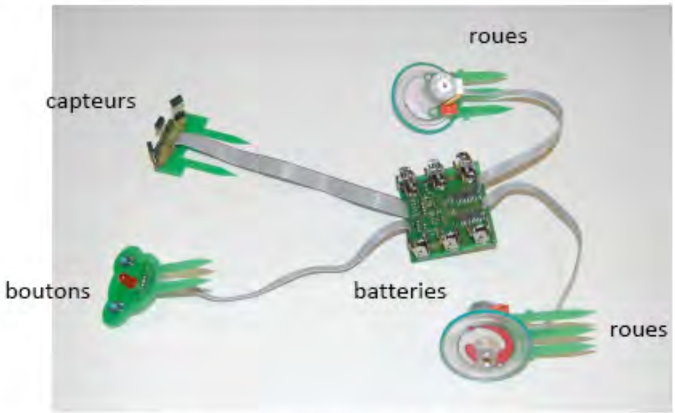


Figure 2: *Premier kit. Prototype 1*

2 DEVELOPPEMENT DE THYMIO

Suite au succès des ateliers avec le kit en 2008, l'équipe de développement a décidé de faire évoluer le concept vers un robot pour enfants distribuable. L'objectif était que les enfants puissent garder le robot après les ateliers contre une légère contribution financière. Il fallait un robot fabricable en série et correspondant aux normes de jouets (notamment électronique non accessible).

L'ECAL s'intéressait à pouvoir offrir un tel robot comme cadeau d'entreprise. Le partenaire industriel chinois était intéressé à présenter ce robot dans des salons de jouets pour pouvoir développer ses compétences dans ce secteur. Le design et les fonctions du robot ont été retravaillées pour arriver à un robot au design très sobre, blanc pour laisser la place à la créativité des enfant reprenant les modules de base : roues, module batteries, module capteurs/boutons combinés.

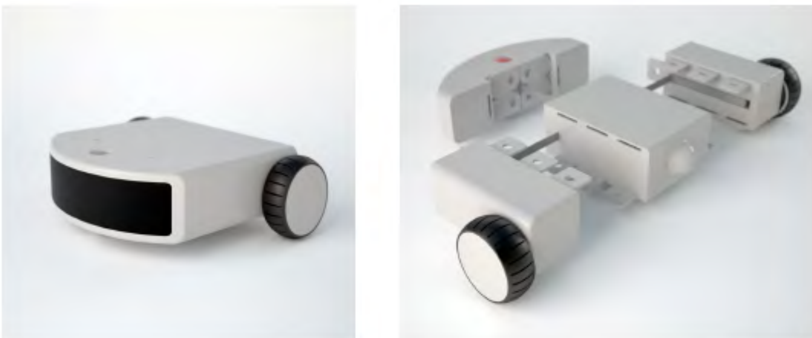


Figure 3: *Thymio*

Le robot présente 3 types de comportement distincts. Des LEDs de couleurs et un speaker permettent de refléter ces humeurs. Le comportement se fait plus interactif et les capteurs sont désormais orientés vers l'avant, vers l'utilisateur. Les 3 comportements finaux sont les suivants :

- Amical – vert : le robot suit l'objet devant lui (typiquement le doigt de l'utilisateur) et s'en approche sans entrer en collision avec. Il affiche l'endroit où il perçoit l'obstacle ;

- Curieux – vert/rouge (Leds verts et rouges allumées simultanément) : le robot avance continuellement en évitant les obstacles ;

- Peureux – rouge : le robot semble éteint et ne s'active que pour fuir lorsqu'on s'approche de lui.

Le packaging se base sur un carton simple avec des dimensions bien choisies qui permettent de monter le robot sur le carton lui-même. Un fourreau porte les inscriptions, ainsi on peut personnaliser la boîte selon le public visé : design enfant pour les ateliers, plus sobre pour l'ECAL. A l'intérieur, un mode d'emploi donne les informations de base et une feuille dans le fond du carton donne des exemples de premier montage à faire avec la boîte. Le nom Thymio vient du grec qui signifie souffle de vie.

Figure 4: *Packaging Thymio*

Le robot est composé de quatre modules en plastique injecté, blanc opaque et transparent, reliés par des câbles non amovibles. La coque des modules est blanche vers l'extérieur, pour permettre une utilisation universelle, et transparente vers l'intérieur, pour permettre aux utilisateurs d'en observer la construction. Les deux jambes (roues, moteur) viennent s'accrocher sur le cœur (batteries, PCB avec microcontrôleur avec pour speaker et commande des moteurs). La tête (PCB avec microcontrôleur pour les capteurs, les LEDs, le bouton de contrôle, les comportements), vient se fixer sur ce bloc. Les modules sont fermés à la soudure ultrason, sauf le cœur qui est collé. Le compartiment batteries est fermé avec une vis.

Figure 5: *Composition de Thymio*

En 2009, près de 400 Thymio ont été distribués lors du Festival de robotique dans un atelier de bricolage (inscription à l'atelier CHF 50.--, chaque enfant pouvait emmener ensuite son robot à la maison). Le robot est produit en Chine, coût de production approximatif **CHF 20.— . En 2010, l'atelier Thymio était à nouveau proposé dans une nouvelle formule. Les enfant pouvaient choisir entre trois thèmes pour l'atelier : construire un robot en forme d'animal, utiliser des techniques de cartonnage ou modifier le robot pour réussir a passer un parcours d'obstacles. Le prix de l'atelier était le même et environ 350 robots ont été vendus.**

Segment d'âge visé : 6 à 12 ans

3 BILAN EXPERIENCE THYMIO 2009 & 2010

Lors des ateliers, les enfants utilisent un montage de base avec du carton et décorent le robot. Selon les feedbacks récoltés, les enfants à leur arrivée à la maison ne démontent plus leur robot bricolé qui reste ainsi dans une armoire. On suppose que les enfants jouent très peu avec leur robot à la maison. Par contre la modularité (3 parties démontables) est un élément qui frappe l'imagination des personnes à qui Thymio est présenté et qui semble avoir beaucoup séduit les acheteurs (qui ne sont pas les utilisateurs de l'objet).

La tranche d'âge visée est manifestement trop large ; les plus petits sont intéressés par les aspects décoration et n'utilisent pas les options de modularité car leur motricité fine ne leur permet pas de le faire sans l'aide d'un adulte. Les plus grands ne trouvent pas la modularité actuelle assez flexible et les fonctions suffisamment complexes, ils se lassent donc vite du comportement jugé trop basique de Thymio et aimeraient pouvoir le programmer.

Dans les deux cas, le côté « n'importe quoi devient un robot » n'est pas du tout exploité. La construction est moins présente qu'avec le premier kit et se limite plutôt à la décoration.

L'objectif de pouvoir utiliser Thymio comme cadeau d'entreprise n'a pas pu être atteint à cause des défauts de qualité dans la production initiale. La soudure ultrason étant réalisée dans des conditions difficilement reproductibles par le sous traitant chinois, la qualité est très variable entre les séries et la qualité très moyenne des robots ne permet pas d'offrir Thymio comme cadeau. Le développement d'un packaging « entreprise » a donc été abandonné.

Les tentatives de présenter le robot aux distributeurs de jouets n'ont pas été concluantes non plus. L'industriel chinois n'a pas pu produire un objet suffisamment convaincant et la certification jouet n'a pas été entièrement obtenue.

Finalement, le coût de revient d'un robot est trop élevé et la qualité trop basse par rapport aux attentes. Le montage est trop complexe et mal pensé à cause des câbles. La modularité qui aurait dû être le point fort du robot n'a pas convaincu les enfants à cause de sa complexité. Les enfants se lassent de Thymio très rapidement car les fonctions proposées sont trop basiques. Les enfants plus âgés aimeraient un robot programmable.

En 2010 le fait de proposer 3 thèmes a permis de voir qu'une séparation se faisait naturellement dans les inscrits. L'atelier « animaux » plutôt orienté décoration a attiré les plus jeunes et plus de filles, l'atelier « parcours d'obstacles » qui mettait plus l'accent sur le challenge à résoudre a été celui qui s'est rempli le plus vite avec des enfants plus âgés.

4 CONCURRENCE JOUET TYPE « ROBOT » POUR ENFANTS

Actuellement, l'analyse de la concurrence s'est essentiellement concentrée sur le produit développé par Lego qui s'appelle Mindstorms™ (http://mindstorms.lego.com/en-GB/default.aspx). Son prix de vente est relativement élevé CHF 479.— et son degré de complexité le rend peu adapté pour des enfants de moins de 9 ans (la first lego league est prévue pour des enfants de 9 à 14 ans). C'est le robot qui est utilisé dans les concours et festivals de robotique mis en place dans la plupart des écoles en Suisse.

Il conviendra dans ce mandat d'identifier les autres acteurs dans ce domaine, leurs offres, les fonctions offertes, les gammes de prix et le type de segmentation par âge proposé afin de mettre en avant les avantages et inconvénients de Thymio.

Aucune analyse spécifique n'a été effectuée par le laboratoire LSRO pour identifier les tendances de développement de jouets « robot » ou incluant une dimension robotique. La mise en avant des grandes tendances dans ce domaine permettra à l'équipe de développement d'avoir des pistes de réflexion pour le développement futur de Thymio (génération 3 et 4).

5 BESOINS DU LABORATOIRE LSRO

En prévision du Festival de robotique en mai 2011, l'équipe du LSRO a décidé de développer une nouvelle génération de Thymio. En effet le stock de Thymio_1 est quasi écoulé et il convient de commander une nouvelle production de meilleure qualité. Pour ce faire et en se basant sur les expériences récoltées lors des différentes manifestations organisées, d'entretiens menés avec des experts, deux scénarii de développement ont été imaginé et mis en image par les designers de l'ECAL.

Cette étude de marché permettra d'identifier quel est le scénario le plus intéressant à produire et qui répond le mieux aux attentes des utilisateurs (les enfants) et des acheteurs (les parents), de valider si les fonctions proposées sont pertinentes. De plus, l'étude permettra de comprendre les freins et motivations rencontrés par les enfants dans l'utilisation de Thymio afin de confirmer les observations réalisées de manière non scientifique et représentative.

L'objectif du laboratoire n'est pas à ce stade de se lancer dans le marché du jeu et de distribuer un robot pour enfant à grande échelle, mais de pouvoir offrir un robot de moins de CHF 100.— permettant d'animer des ateliers et manifestations avec des enfants afin de sensibiliser ces derniers à la science et aux nouvelles technologies.

6 BUTS DU MANDAT

Les objectifs de ce mandat sont de :

1. Analyser le marché du robot pour enfants et des grandes tendances dans le domaine du jeu « robotique »
2. Identifier et analyser les concurrents directs et indirects : quels sont les différents acteurs, taille du marché potentiel, gamme de prix, offres actuelles, avantages et inconvénients vs Thymio dans un contexte d'*edutainment*
3. Valider si le fait de segmenter le marché en deux tranches d'âge fait sens : 6 à 9 ans et 10 à 13 ans
4. Identifier et analyser les freins et motivations des utilisateurs et acheteurs par rapport à Thymio_1
5. Valider auprès des utilisateurs, acheteurs potentiels et des experts les scénarios de développement de Thymio_2 : quel scénario développer et pourquoi ? Fonctions ajoutées sont-elles pertinentes ? Fourchette de prix psychologique par scénario ?

Cette étude de marché s'inscrit dans une démarche exploratoire et prospective. Il s'agit donc de privilégier une approche qualitative. Il est rappelé que les résultats obtenus ne pourront pas être extrapolés à l'ensemble des univers considérés. Au vu des limites temporelles et géographiques dans lequel s'inscrit cette étude, les entretiens seront essentiellement réalisés en Suisse romande et plus particulièrement dans le canton de Vaud.

Documents à fournir par le mandant :

Des visuels devront être livrés aux étudiants pour les aider à réaliser les entretiens, condition *sine qua non* dans le cadre d'une étude de marché basée sur une innovation technologique. Délai pour la livraison des visuels : mi-octobre 2010 au plus tard.

- Base de données des enfants ayant participés au Festival robotique et achetés Thymio_1
- Etudes de marché déjà réalisées : synthèse des résultats du questionnaire expo.02 et celui réalisé dans le cadre du Festival de robotique en 2009 et 2010
- Liste des experts clés à contacter
- Articles spécialisés dans le domaine

Délivrables principaux pour le mandant

- Recommandation pertinente quant au choix du scénario pour le développement de Thymio_2 ;
- Evaluation chiffrée et commentée du marché du jouet « robot » pour enfant, avec une liste des principaux acteurs et une comparaison avec grille d'analyse des points forts et faibles de Thymio. De plus, les grandes tendances dans le domaine de l'edutainment des jouets « robot » sont présentées afin de proposer des pistes de réflexion pertinentes pour le développement à moyen terme de Thymio;
- Explication et quantification des freins et motivations d'achat pour Thymio_1 auprès des acheteurs et utilisateurs. L'hypothèse que Thymio reste dans une armoire dès le retour des enfants à la maison sera confirmée ou infirmée.

7 ETAPES DU MANDAT

Ce mandat comprend plusieurs modules (ci-après désignés WP : Work Packages) résumés comme suit :

No.	Objectifs, contenus et livrables	Coûts
WP1	**Analyse de la situation actuelle & tendances futures** - Dans un premier temps, les élèves devront s'immerger dans ce domaine particulier en privilégiant des entretiens préliminaires avec le Dr Francesco Mondada de l'EPFL, Mme Fanny Riedo, ingénieur et chef de projet et le designer Luc Bergeron de l'ECAL. Ceci afin de bien identifier la problématique et les préparer aux entretiens qualitatifs des WP3, 4 et 5. - De plus, les étudiants devront identifier par une recherche documentaire les tendances actuelles du marché du jouet robot pour enfant. *Livrables :* - Un rapport présentant les grandes tendances dans le domaine du jouet « robot » pour enfant	---- CHF

WP2	**Analyse de la concurrence directe et actuelle** - Chaque groupe devra présenter un état des lieux de la concurrence directe et indirecte en matière de jeux « robot » pour les enfants de moins de 13 ans afin de mettre en évidence les forces et faiblesses de Thymio 1 et 2. - Il s'agira de lister tous les acteurs dans le domaine, le type de jouets offerts, les fonctions présentées, le niveau de complexité, le type de segmentation proposée (fille/garçon, tranche d'âge,…), les gammes de prix, le positionnement (éducatif, aventure, gadget,…), le marché potentiel (à quantifier). - La méthodologie à privilégier sera la récolte de données secondaires via Internet et l'observation *in situ* dans des magasins de jouet en Suisse romande. Des entretiens semi-directifs de courte durée en face à face seront également réalisés auprès des vendeurs des magasins pour les questionner sur les tendances et l'évolution du marché. - Chaque groupe d'étudiants réalisera au minimum un entretien semi-directif en face à face ou téléphonique de 20 à 45 mn maximum auprès de maîtres de science & robotique d'écoles secondaires pour identifier les forces et faiblesses du robot Mindstorms™. *Livrables :* - Liste des concurrents directs et indirects - Tableau comparatif avec critères d'analyse permettant d'identifier clairement les forces et faiblesses de Thymio - Etat des lieux de la concurrence dans le domaine des jeux « robot » pour enfant de 6 à 13 ans	---- CHF

WP3	**Identification des freins et motivations d'achat et d'utilisation de Thymio_1** - Chaque groupe interviewera deux acheteurs de Thymio_1 via un entretien semi-directif en face à face ou téléphonique. Il s'agira de privilégier des parents ayant des enfants de moins de 10 ans et des parents ayant des enfants de plus de 10 ans. Ces entretiens serviront de base pour la réalisation du questionnaire quantitatif. - Lors des entretiens avec les experts, les fonctionnalités de Thymio_1 seront systématiquement présentées afin de confirmer ou infirmer les hypothèses posées. - Mise sur pied de deux focus groups réunissant 8 enfants des deux tranches d'âge considérées et présentation systématique de Thymio_1 pour identifier motivations et freins potentiels. Attention : accord parental doit être systématiquement demandé par écrit. - Envoi d'un questionnaire quantitatif (on-line si possible) aux parents ayant acquis un Thymio_1 via les ateliers du Festival. Univers de référence à définir selon le nombre d'adresses. Intervalle de confiance et marge d'erreur seront déterminées *a posteriori* selon le nombre de questionnaires retournés. Ce questionnaire permettra de quantifier et mesurer un certain nombre d'hypothèses. *Livrables :* - Rapport d'analyse et de compte rendu des entretiens menés (ce document sera intégré au rapport final). - Description des fonctions potentiellement intéressantes à développer relevées lors des entretiens qualitatifs.	---- CHF

WP4	**Choix du meilleur scénario de développement pour Thymio_2** - Chaque groupe interviewera des parents (une fois possédant le Thymio_1, une fois ne possédant pas Thymio_1) via un entretien semi-directif en face à face. Ces entretiens permettront de valider le choix du meilleur scénario de développement pour Thymio _2. - Lors des entretiens avec les experts, les scénarios de développement Thymio_2 seront présentés afin d'identifier le scénario présentant le potentiel le plus intéressant. Les fonctions seront validées. Objectif : un entretien par étudiant. - Réalisation de deux focus groups réunissant 8 enfants des deux tranches d'âge considérées et présentation des scénarios de développement de Thymio_2. Entretien de 1h00 – 1h30 environ. Attention : accord parental doit être systématiquement demandé par écrit. *Livrables :* - Un rapport d'analyse et de compte rendu des entretiens menés (ce document sera intégré au rapport final). - Une liste des fonctions indispensables et accessoires pour Thymio_2.	---- CHF

WP5	**Construction du questionnaire et guides d'entretiens** - Les étudiants déterminent les items à utiliser pour obtenir les informations nécessaires à la réalisation du mandat. - Les hypothèses pour chaque type d'entretiens devront être présentés et validés par le professeur. - Les interviews seront menées sur la base de guides d'entretien validés par le professeur et le mandant. - Les interviews s'effectueront en face à face ou par téléphone. La durée d'une interview sera de 10 à 45 minutes maximum. *Livrables :* - Un rapport d'analyse et de compte rendu des entretiens menés (ce document sera intégré au rapport final). Les comptes rendus sous forme de procès-verbal (*verbatim*) de tous les entretiens qualitatifs seront ajoutés dans le dossier Annexe joint au rapport principal.	---- CHF

WP6	**Rapport d'analyse sur la base de l'enquête par questionnaire et de l'enquête qualitative** - Les étudiants présentent et interprètent les résultats des différentes enquêtes. Les étudiants intègrent les résultats sous encadrement. Sur cette base, ils réalisent une évaluation concernant les dimensions investiguées et formulent des recommandations. *Livrables :* - Un rapport d'analyse de la situation et d'évaluation, assorti de recommandations.	---- CHF

TOTAL (HT)	**--- CHF**
TVA (7.6 %)	---- CHF
TOTAL (TTC)	**---- CHF**

8 REMARQUES

1. Le concept d'intervention proposé est susceptible d'être modifié selon les vœux du mandant.
2. Le volume d'heures présenté dans cette offre a été estimé sur la base des informations connues au moment de la rédaction de celle-ci. Si le mandant ou le mandataire estime que les heures indiquées dans la présente offre ne sont pas suffisantes pour achever le mandat, il sera procédé à une renégociation de l'offre entre les parties, au fur et à mesure de l'avancement de celui-ci.

9 RESPONSABLE DU MANDAT

Mme Nathalie Nyffeler, Prof. HEIG-VD, coordonnées en en-tête.

10 DELAIS

No. WP	Début	Fin
WP1	21.09.10	04.10.10
WP2	21.09.10	15.10.10
WP3	11.10.10	01.12.10
WP4	11.10.10	01.12.10
WP5	11.10.10	01.12.10
WP6	22.12.10	10.01.11

11 RENSEIGNEMENTS GENERAUX

11.1 COUTS

Non applicable dans ce cadre

La responsable de projet rappelle cependant qu'elle ne peut pas garantir le résultat de travaux effectués dans un cadre académique.

11.2 LOGISTIQUE

A la charge du mandant. Le mandant s'engage à mettre les ressources nécessaires à disposition pour la collecte des réponses.

11.3 VALIDITE

30 jours dès réception de l'offre.

11.4 PAIEMENT

Non applicable.

11.5 CONDITIONS PARTICULIERES

Les informations confidentielles seront traitées comme telles.

La HEIG-VD pourra citer la raison sociale de votre société en tant que référence client. Les étudiants pourront mentionner la participation à ce travail dans leur CV.

Dans le but de mettre en valeur les activités de l'école, l'objectif du mandat pourra être mentionné, sans trahir l'essence du secret des affaires, sur les supports de mise en valeur des activités de la HEIG-VD.

Lu et approuvé :

Lieu et date :		
Signature(s) :		
Nom(s) :		
Pour :	Dr Francesco Mondada Maître en Enseignement et Recherche EPFL	Nathalie Nyffeler Professeur Haute Ecole d'Ingénierie et de Gestion du canton de Vaud (HEIG-VD) 1401 Yverdon-les-Bains

C Questionnaire for WSSURVEY11

Profile

birth date

gender

Would you have preferred a boy-only/girl-only workshop? (yes/no)

Appreciation

Give a general appreciation grade to this workshop (1 to 6)

Give a grade to the hardware (1 to 6)

Give a grade to the supervision (1 to 6)

How would you characterize this workshop? (educational, funny, interesting)

How did you choose this workshop? (multiple answers possible) (discussion with friends/family, description, discussion with festival staff, price, duration, availability)

Have you already taken part in other workshops? (no, this year, in 2010, in 2009, in 2008)

Learnt concepts

Were you surprised by the robots you saw today?

- Yes, they are able to do things I thought impossible for a robot
- Yes, they are unable to do things I thought possible for a robot
- Yes, because they are different from other robots

- No, they are like I imagined them
- No, I already saw them

What is a robot exactly?

- An automaton that runs a program moving it regardless of the outside world
- A device that measures physical values and allows to visualize them
- A device able to perceive the world, and to react given what it has seen
- A mobile device that randomly moves in function of pre-defined parameters

What are the characteristics of a sensor?

- It measures things around the robot
- It shows what the robot does
- It allows the robot to change its environment
- It tells the robot what is around
- It allows robots to communicate with each other

At which distance can Thymio II detect obstacles?

- I do not know
- When it touches them
- At 2 cm
- At 5–10 cm
- At 10–50 cm
- At more than 50 cm

How does Aseba allow to program a robot?

- The robot sends information to the computer, that handles it, and that sends commands to the robot
- The robot controls the computer; depending on what the robot perceives, the computer runs different programs

- I was not able to program the robot using Aseba, therefore I do not understand how it works
- I write the program on the computer, and the program runs on the robot

What is a variable?

- An object from the world, like a table, a chair, a wall
- A value in the robot's computer that can represent something from the world or something abstract
- A number, like 3 or 9.81, that represents a physical constant, like gravity
- A text in Aseba Studio, that is replaced by constants when the program is sent to the robot

What is a if?

- A word that tells the robot to take a decision in function of the value of a variable
- An English word that I do not understand, I would like Aseba to speak French
- A word that allows to put a value inside a variable
- A word that allows to execute many times the same program part

D Questionnaire for TEACHERSURVEY11

D.1 Profile

- Firstname
- Lastname
- email
- Sector where you are active (compulsory education, baccalaureate schools, vocational education, teacher training and applied sciences universities, university, industry, associations or foundations, others)
- Channel of information about this initiative (personal email or direct contact, colleagues, mailinglist, school, information meeting, media, web, other)
- Attended workshops (give the list)
- Discipline where you would like to apply what you learned (Computer science, maths, sciences, languages, handiwork, history or geography, other)

D.2 Evaluation

Indicate the quality of the following aspects:

- E1: Web site for the teachers (bad, insufficient, sufficient, good, excellent)
- E2: Training for the workshop (bad, insufficient, sufficient, good, excellent)
- E3: Organization of the event (bad, insufficient, sufficient, good, excellent)
- E4: Written educational material (bad, insufficient, sufficient, good, excellent)

- E5: Global appreciation (bad, insufficient, sufficient, good, excellent) Impact of the event.

Position yourself in respect to the following sentences:

- P1: I am always looking for new technologies for my teaching activity / promotion of sciences (no, rather no, rather yes, yes)
- P2: I already use the type of educational tools seen at the festival (no, rather no, rather yes, yes)
- P3: The participation to the workshops is an excellent training opportunity (no, rather no, rather yes, yes)
- P4: I appreciated to be able to check the use of the presented tools (no, rather no, rather yes, yes)
- P5: It is important to receive the material (robot, kit) at the end of the workshop (no, rather no, rather yes, yes)
- P6: It is important to be able to use the material in my class (No, rather no, rather yes, yes)
- P7: I was able to visit the others activities of the festival, such as shows and exhibitions (No, rather no, rather yes, yes)
- P8: I will for sure use what I learned in my activity (No, rather no, rather yes, yes)
- P9: I am motivated to develop new educational documents/activities to use these technologies in my classes (No, rather no, rather yes, yes)

Future of the event.

- If we repeat this action, are you interested in participating? (yes, no)
- Would you encourage your colleagues to participate to the workshop as you did? (yes, no)

E Questionnaire for WSSURVEY12

Questionnaire en début d'atelier

Numéro du robot

Numéro du ticket

As-tu déjà fait un atelier Thymio II?
- Oui
- Non

As-tu déjà joué avec un Thymio II?
- Oui
- Non

As-tu déjà fait de la programmation?
- Oui
- Non

Que sait faire un robot mobile miniature comme le thymio ?
- prendre des décisions en fonction de ce qu'il perçoit
- réagir aux événements extérieurs
- combattre les extra-terrestres
- émettre des sons
- comprendre quand on lui parle
- mixer les fruits
- communiquer avec l'ordinateur
- faire de la lumière
- percevoir et éviter les obstacles
- se déplacer dans plusieurs directions

Questionnaire en fin d'atelier

Numéro du ticket

Que sait faire un robot mobile miniature comme le thymio ?
- prendre des décisions en fonction de ce qu'il perçoit
- réagir aux événements extérieurs
- combattre les extra-terrestres
- émettre des sons
- comprendre quand on lui parle
- mixer les fruits
- communiquer avec l'ordinateur
- faire de la lumière
- percevoir et éviter les obstacles
- se déplacer dans plusieurs directions

Qu'as-tu fait pendant l'atelier?

- Jouer avec les modes de base (couleurs)
- Utiliser les capteurs de proximité
- Changer la couleur du robot
- Faire bouger le robot
- Utiliser les LEDs
- Débrancher le robot pour tester son comportement
- Détecter les chocs
- Eviter de tomber en bord de table
- Utiliser l'accéléromètre
- Faire un graphique pour visualiser les variables
- Eviter les obstacles
- Autre chose:

A quelle distance thymio peut-il détecter des objets?

- Il ne peut pas les détecter
- Seulement s'il les touche
- Jusqu'à 10 cm au maximum
- Jusqu'à 50 cm au maximum
- Je ne sais pas

A quoi sert un capteur?

- Il montre ce que fait le robot
- Il permet au robot de changer son environnement
- Il informe le robot de ce qu'il y a autour
- Je ne sais pas

Comment Aseba permet-il de programmer le robot?

- Le robot envoie des informations à l'ordinateur qui les traite, puis qui envoie des commandes au robot.
- Le robot contrôle l'ordinateur ; selon ce que le robot perçoit, l'ordinateur exécute différents programmes.
- J'écris le programme sur l'ordinateur, puis le robot exécute le programme.
- Je ne sais pas / je n'ai pas compris.

Qu'est-ce qu'un if?

- Un mot clé qui dit au robot de prendre une décision en fonction de la valeur d'une variable.
- Un mot anglais que je ne comprends pas, je préférerais qu'Aseba soit en français.

- Un mot clé qui permet de mettre une valeur dans une variable.
- Un mot clé qui permet d'exécuter plusieurs fois un morceau de programme.
- Je ne sais pas.

F Questionnaire for WSSURVEY13

Atelier N°25: **Découvrir Thymio II en s'amusant !**

1. **Quel est ton age?** ....
2. **Coche la réponse qui te convient:**

☐ je suis une fille ☐ je suis un garcon

3. **Est-ce la première fois que tu viens au festival?**

☒ oui ☐ non

Si non, combien de fois es-tu déjà venu(e)? ....

4. **Est-ce la première fois que tu fais un atelier Thymio?**

☒ oui ☐ non

5. **Pour quelle(s) raisons es-tu là aujourd'hui au festival? Coche la ou les réponses:**

☒ parce que mes parents ont décidé
☐ pour prendre du plaisir à découvrir des robots
☐ parce que plus tard je veux travailler dans la technique
☐ pour faire comme mon frère/soeur ou mes ami(e)s
☐ je ne voulais pas venir

6. **As-tu choisi seul(e) de t'inscrire à cet atelier?**

☐ oui ☐ non

Si non, qui a choisi pour toi ?

☐ papa ☐ maman ☐ autre ....

7. **Qu'as-tu apprécié dans cet atelier que tu viens de suivre?**

☐ rien du tout
☐ je pouvais jouer
☐ les consignes et défis étaient stimulants
☐ j'ai appris des choses qui me serviront plus tard

8. **As-tu réussi les défis?**

☐ pas du tout ☐ un peu ☐ beaucoup

9. **L'activité était-elle trop difficile?**

☐ pas du tout ☐ un peu ☐ beaucoup

10. **Est-ce facile de savoir sur quel bouton de Thymio appuyer, par exemple pour que Thymio suive une piste?**

☐ pas du tout ☐ un peu ☐ beaucoup

11. **Aimes-tu ce qui est technique?**

☐ pas du tout ☐ un peu ☐ beaucoup

Pourquoi ? ....

12. **Parmi les jouets suivants, lesquels sont "techniques" selon toi ?**

☐ Lego ☐ Playmobil ☐ voiture télécommandée

13. **Que ferais-tu avec Thymio si tu l'avais à la maison?**

....

14. **En venant au festival aujourd'hui, quel était ton but premier?**

☐ rien
☐ m'amuser
☐ apprendre de nouvelles choses
☐ rencontrer des gens
☐ accompagner quelqu'un

15. **Est-il atteint ?**

☐ pas du tout ☐ un peu ☐ beaucoup

G Questionnaire for ETHSURVEY13

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Autonomous Systems Lab

Questionnaire on Programming in Aseba / VPL

Dear student/pupil,

We are doing research on the effectiveness of the Thymio-II robot and the Aseba / VPL software for learning robotics and computer science.

We would very much appreciate your help in this research. Please answer the following multiple-choice questions to the best of your ability. Start from the beginning and answer as many questions as you can in the time available. For every question, please circle the right answer.

You are not required to do this and we will only use the results for our research. We are not asking for your name and the results will not be given to your teachers or parents.

Thank you for your time and effort,

Dr. Stéphane Magnenat, Dr. Jiwon Shin, Prof. Moti Ben-Ari

Please provide the following information about your background:

1. I am .... years old.
2. I have experience programming: yes / no.
   If yes, I have been programming for .... years.
3. I have experience building or using robots: yes / no.
   If yes, I have been using them for .... years.

Recall the meaning of the ground and horizontal distance sensors:

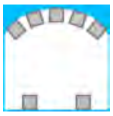
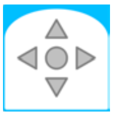
Horizontal distance sensor

- **White square**: an event will occur if there is **nothing nearby**;
- **Red square**: an event will occur if there is **something nearby**.

Ground sensor

- **White square**: an event will occur if **there is no ground** or if **little light is reflected** from the ground (for example, if it is black);
- **Red square**: an event will occur if **there is a ground** and **a lot of light is reflected** from the ground (for example, if it is white).

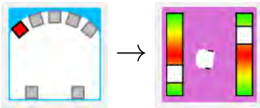
1. For each block, tell whether it is an **Event block** or an **Action block**:

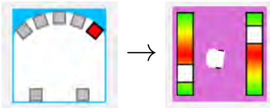
	Event block	Action block
	Event block	Action block
	Event block	Action block
	Event block	Action block
	Event block	Action block

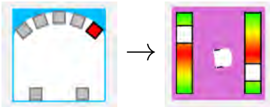
2. For each event-action pair, tell whether it is **Correct** (valid) or **Wrong** (not valid):

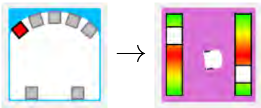
 → 	Correct	Wrong
 → 	Correct	Wrong
 → 	Correct	Wrong
 → 	Correct	Wrong

3. Which one of these event-action pairs causes the robot to **turn right** when the **left sensor** detects an object?

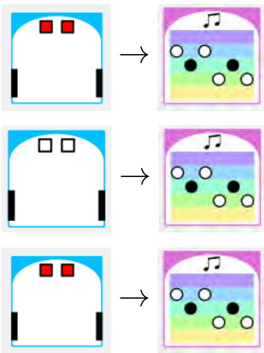
   (a) 

   (b) 

   (c) 

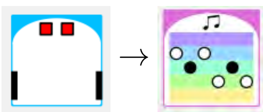
   (d) 

4. Is something **wrong** with this program?

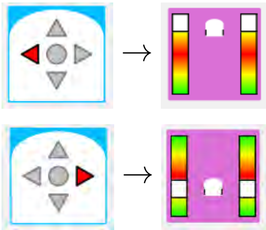
   (a) Yes, you **can't have** two event-action pairs with exactly the **same event**.
   (b) Yes, you **can't have** two event-action pairs with exactly the **same action**.
   (c) Yes, you **can't have** two event-action pairs that are **exactly the same**.
   (d) No, **Nothing is wrong** with the program.

5. What does this event-action pair **do**?

   (a) **Play** music if **both** ground sensors are over a **black** ground.
   (b) **Stop playing** music if **both** ground sensors are over a **white** ground.
   (c) **Play** music when the **program starts** to run.
   (d) **Play** music if **one** sensor is over a **white** ground and **one** is over a **black** ground.
   (e) **Play** music if **both** ground sensors are over a **white** ground.

6. In the following program:



What happens if you touch the **left button**, then touch the **left button again** and then touch the **right button**?

(a) You **can't touch** a button **twice** in a row.

(b) The robot moves **forwards** because you touched the **left** button **more times** than you touched the **right** button.

(c) The robot moves **backwards** because it **ignores** the **first two touches** and only **does** the action of the **last** event-action **pair**.

(d) The robot moves **forwards** and **then** it moves **backwards**.

7. Running the action block  causes the two **motors** to:

(a) Run at the **same speed**.

(b) Run at different speeds: the **left** motor runs **faster**.

(c) Run at different speeds: the **right** motor runs **faster**.

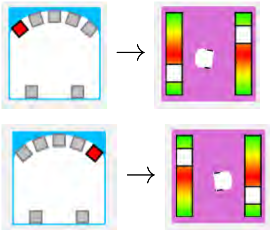
Running the action block  causes the **robot** to:

(a) Go **straight**.

(b) Turn **right**.

(c) Turn **left**.

8. What happens if you run the following program and place an **obstacle** in **front** of the **leftmost sensor**?



(a) The robot **turns left** until the **right sensor** detects the **obstacle** and then **turns right**. This goes on **indefinitely**.

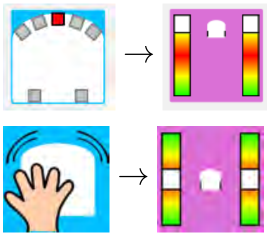
(b) The robot **turns right** until the **right sensor** detects the **obstacle** and then **turns left**. This goes on **indefinitely**.

(c) The robot **turns right** until the **right sensor** detects the **obstacle** and then **stops**.

(d) The robot **turns left** until the **right sensor** detects the **obstacle** and then **stops**.

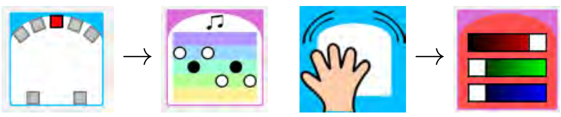
(e) The robot **doesn't move** because it will only move when both the left and right sensors detect an obstacle at the same time.

9. The following program lets the robot **approach a wall** and **stop when** the robot **hits** the wall:



Which two event-action pairs must be **added** to the program so that the robot turns the **top light red** when it **detects the wall** and **plays** music when it **hits the wall**?

(a) 

(b) 

(c) 

(d) Either (a) or (c)

(e) Either (a) or (b)

(f) Either (b) or (c)

H Questionnaire for SCHOOLDAY14

Sexe: Masculin ☐ Féminin ☐

Age: ________ ans

J'ai un robot jouet à la maison: Oui ☐ Non ☐

J'ai un robot ménager à la maison: Oui ☐ Non ☐

Question 1: Si tu pouvais choisir de recevoir un robot pour Noël, lequel de ces deux tu choisirais (pour le même prix):

Connais-tu déjà ce robot? Oui ☐ Non ☐

Je choisirais celui-ci ☐

Ce robot est plus ____________________

____

Connais-tu déjà ce robot? Oui ☐ Non ☐

Je choisirais celui-ci ☐

Ce robot est plus ____________________

____

Question 2: On va te montrer une vidéo qui présente le robot Thymio.

Indique 3 composants que tu penses être les éléments essentiels qui permettent à ce robot de fonctionner:

1. ____

2. ____

3. ____

Question 3: Tu as pu te familiariser avec le robot Thymio et tu le connais un peu mieux.

Indique 3 composants que tu penses être les éléments essentiels qui permettent à ce robot de fonctionner:

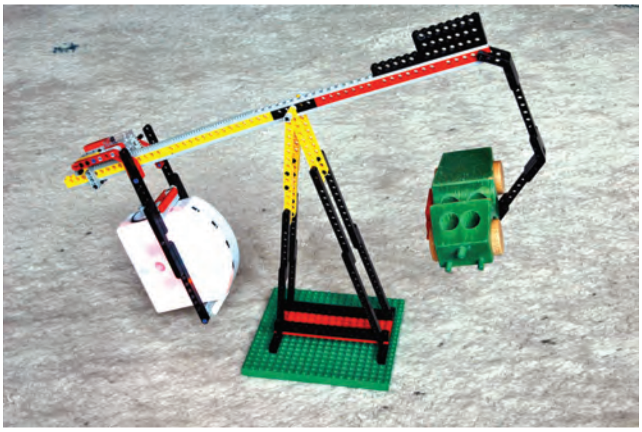
1. ______________________________

2. ______________________________

3. ______________________________

Question 4: A l'école tu as eu l'occasion d'étudier les levier, les forces ... On peut étudier ces concepts avec le robot Thymio. Voici deux exemples de balance, avec une vidéo en projection.

Si on te mettais à disposition tout le matériel nécessaire, laquelle des deux balances tu aimerais construire et tester?

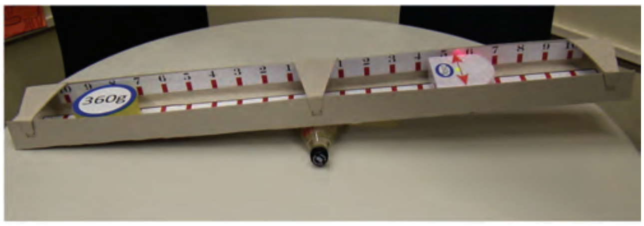


Je choisirais celle-ci ☐

Cette balance est plus ______________

____

____



Je choisirais celle-ci ☐

Cette balance est plus ______________

____

____

Merci pour tes réponses!

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FANNY RIEDO

PERSONAL INFORMATION

Born in Switzerland, 3 September 1982

email fanny.riedo@gmail.com

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WORK EXPERIENCE

2010–2014 Scientific assistant / Phd Student, LSRO, EPFL

Robotic Systems Laboratory, EPFL

Management of the Thymio II project (design and first production line in Shenzhen, China - more than 5000 robots produced and sold to the general public. Development of electronics, software, and mechanical design. Scientific outreach activities. Supervision of master and bachelor students (projects and lectures). Research on pedagogical and social impact of robots in education.

2008–2010 Scientific Assistant, EPFL+ECAL Lab / LSRO, EPFL

EPFL+ECAL Lab / Robotic Systems Laboratory, EPFL

Development and Production supervision of the Thymio Robot (1000 units). Project manager (engineering and technical aspects) for international exhibitions Give Me More (DMY International Design Festival Berlin award in 2010) and Sunny Memories (collaborations between EPFL, écal and other international design schools). Hardware and software development. Outreach activities. Supervision of master, bachelor and CAS students (projects and lectures).

2007 Scientific Assistant, LIS, EPFL

Laboratory of Intelligent Systems, EPFL

Research on the artificial evolution of neural networks capable of computing optical flow.

EDUCATION

2010-2015 Ecole Polytechnique Fédérale de Lausanne

PhD in Robotics

Doctoral School: Systèmes de production et robotique
Thesis: *Thymio: a holistic approach to designing accessible educational robots*
Description: This thesis explored the potential of robots as educational tools for children.
Advisors: Prof. Francesco Mondada & Prof. Pierre Dillenbourg

2002-2007 Ecole Polytechnique Fédérale de Lausanne

Master of Sc. in Microengineering

Specialisation in Robots and Autonomous Systems · School: Microengineering

1998-2002 Collège Sainte-Croix, Fribourg

Baccalaureate

Specific option: Greek · Advanced Mathematics · Complementary Option: Chemistry

COMPUTER SKILLS

Software	MPLab, ProEngineer, Altium Designer, Matlab, R, Git, SVN
Programming Languages	C/C++ (Qt), Java, Assembly, VHDL
OS	Mac OS, Ubuntu, Windows

OTHER INFORMATION

Side Projects - Interactive Installations

2010 · TURNING PLATES · Hardware support for interaction designer Camille Scherrer's installation.

2010 · LA SALAMANDRE · Interactive installation for visitors at Festival La Salamandre in Morges with Camille Scherrer.

2009–2010 · OH MY GOD · Demonstration setup of evolutionary robotics at the Oh My God exhibition (Lausanne museum of Zoology) with Julien Hubert, Sara Mitri and James Roberts.

Languages

FRENCH · Mother tongue

ENGLISH · Fluent

GERMAN · Intermediate (good comprehension, medium expression)

RUSSIAN · Basic (simple conversations)

JAPANESE · Basic (simple conversations)

Interests

Dancing · Painting

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December 22, 2014