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Why it is harder to run RoboCup in South Africa: Experiences from German South African collaborations

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Abstract

Robots are widely used as a vehicle to spark interest in science and technology in learners. A number of initiatives focus on this issue, for instance, the Roberta Initiative, the FIRST Lego League, the World Robot Olympiad and RoboCup Junior. Robotic competitions are valuable not only for school learners but also for university students, as the RoboCup initiative shows. Besides technical skills, the students get some project exposure and experience what it means to finish their tasks on time. But qualifying students for future high-tech areas should not only be for students from developed countries. In this article, we present our experiences with research and education in robotics within the RoboCup initiative, in Germany and South Africa; we report on our experiences with trying to get the RoboCup initiative in South Africa going. RoboCup has a huge support base of academic institutions in Germany; this is not the case in South Africa. We present our 'north–south' collaboration initiatives in RoboCup between Germany and South Africa and discuss some of the reasons why we think it is harder to run RoboCup in South Africa.

Keywords

Educational robotics, north–south collaboration, RoboCup

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Introduction

Robotics is widely accepted as a vehicle to spark interest in science and technology in learners. The introduction of robot technology in the classroom alone is, however, only part of the solution. Good curricula which include robot technology need to be developed.[1] A large number of initiatives, therefore, try to engage learners with robot technology in competitions, where they have to solve certain tasks with robot technology, and are quite successful with it. Some of these initiatives are the Roberta Initiative (`http://www.roberta-home.de/en/`), the FIRST Lego League (`http://www.first-lego-league.org/`), the World Robot Olympiad (`http://www.wroboto.org/`) and RoboCup Junior (`http://www.robocupjunior.org/`). These kinds of initiatives are not only available in developed countries, but are also very active in developing countries. Dias et al.[2] present a case study on robotics education in developing countries. Their claim is that robotics education could support the empowerment of students from developing countries. Among other factors,

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they pinpoint that local and global partnerships, shared resources (due to technology costs), empowerment and sustainable programs are cornerstones for successful initiatives. A case study from Chile[3] discusses how contests in robotics can foster research activities in developing countries. One such robotics initiative which uses the competition idea is the RoboCup initiative; it offers competitions for university students and builds on an active research community to meet the RoboCup vision to win against the then-reigning football (soccer) world champion team with a team of humanoid robots by 2050. It also has a RoboCup Junior branch which focuses on learners in the age group between 10 and 19 years. The outreach of this initiative is huge with thousands of learners and students including PhD students and academic staff participating in these competitions. The success of RoboCup after 10 years was described by Visser and Burkhard[4] and it has grown ever since. Many research activities use RoboCup as their testbed and research results from RoboCup are disseminated in international conferences and journals.

However, interest in RoboCup varies from one region of the world to another; RoboCup is not equally popular and successful everywhere. Also, it might serve different purposes in different regions of the world and different countries might emphasise different aspects. RoboCup offers competitions for seniors (university students and academic staff) and for school learners. RoboCup Junior is the branch of RoboCup which aims to engage young learners in science and technology. One concept for teaching technology to learners is to follow a project-based approach as is done with RoboCup. The advantages of such a project-based education for teaching robotics in the context of RoboCup are discussed by Verner.[5] Another article analyses the success of RoboCup Junior after 10 years of competitions.[6] A positive effect of RoboCup Junior (and of RoboCup) is that learners make contact with learners from other nationalities and cultural backgrounds. In the article by Eguchi,[7] for instance, international collaborations that resulted from the RoboCup Junior dance tournament are reported on. RoboCup Junior was also proposed as an educational initiative for Africa.[8] In our previous work, we proposed how RoboCup Junior could be established in South Africa.[9] We also made a proposal for an educational robot[10] that is suitable for science and technology education in the African context. Besides our platform, a number of other teaching robot platforms exists. An overview of different platforms for teaching computer science content with robots in the African context is given by Gyebi et al.[11]

In spite of the possibilities and the seemingly positive impact of RoboCup for education and research, we observe that the interest in participating in RoboCup competitions differs between Germany and South Africa, the two countries in which the authors have a good overview of the robotics activities. The authors have long-standing experience with leading student teams in RoboCup competitions. Nearly 10 years ago, enthusiastically and convinced of the positive impact of RoboCup, we started to raise interest in RoboCup in South Africa. With the help of a seed fund from the German and South African governments, we wanted to establish RoboCup teams at South African universities. Four universities received funding for building robots for the RoboCup Small-Size League (SSL), a RoboCup league where small, partly autonomous robots play soccer against each other (also see Utete et al.[12]). To support this process, further collaboration projects between our Aachen RoboCup team and the team from the University of Cape Town (UCT) were initiated. Together with colleagues from the University of Graz, Austria, and colleagues from UCT, we initiated a RoboCup team that participated in the Standard Platform League, a league where two teams of up to three humanoid Nao robots play soccer against each other. This team participated three times in international RoboCup competitions. These three universities (Cape Town, Graz and Aachen) also supported the first South African RoboCup Junior entry in the 2010 RoboCup in Singapore. Besides these competition entries, the RoboCup team from UCT also entered the competition in the RoboCup Rescue League once in 2012. From the German–South African funded small-size teams, unfortunately, none made it to international competitions. While RoboCup is very successful in Germany, it is, despite the efforts of the authors, not taking over in South Africa.

In this article, we report on the different RoboCup projects focusing on our 'north–south' collaboration projects. We give an overview of different performance indicators such as team size, funding and scientific output of the different projects and compare our projects based on these indicators. From our perspective and experience, we discuss some of the possible reasons why the RoboCup competition has not (yet) taken over in South Africa. The remainder of this article is organised as follows. In the next section, we briefly introduce the RoboCup initiative. In 'Involvement in RoboCup teams', we present the collaboration initiatives between Germany and South Africa and discuss whether or not the particular project was successful based on the given indicators in 'Performance in RoboCup and lessons learnt'. We conclude with a discussion on why we believe RoboCup could not yet be established in South Africa.

The RoboCup initiative

In the early days of artificial intelligence (AI) research, it was believed that within one or two decades human intelligence could be understood and be rebuilt within computer systems. The excitement was huge and so were the promises of what AI could deliver. It turned out, however, that AI could not deliver as expected. Moreover, tasks such as chess, which were believed to be a key application for understanding human intelligence, were solved by sheer computing power (e.g. Crevier[13] and Gaskin[14]). In the 1990s, some of the paradigms of AI shifted towards autonomous intelligent systems interacting with real-world human environments. In 1997, Kitano et al.[15] proposed

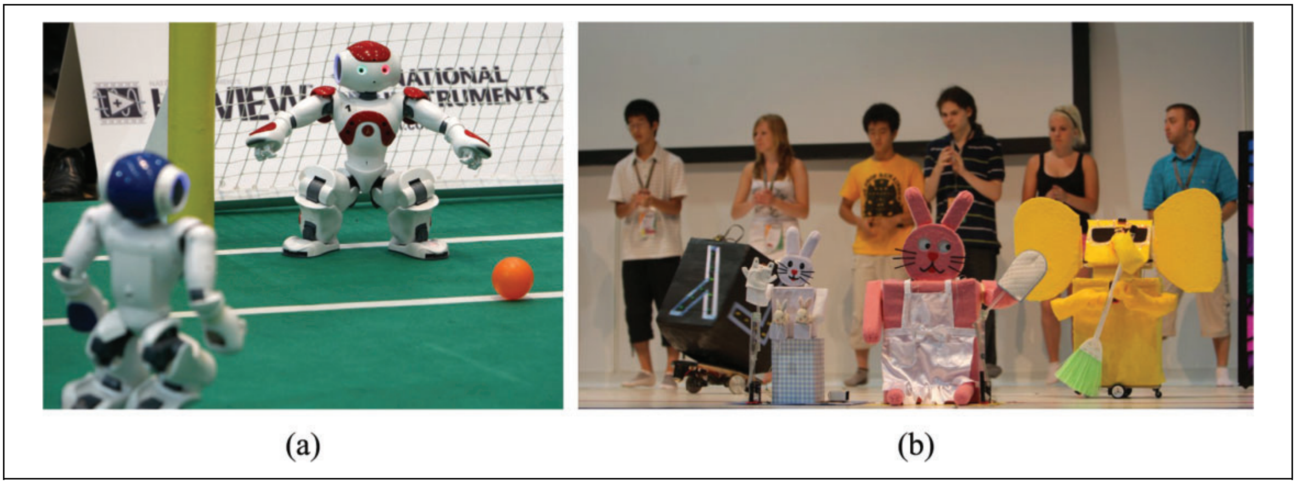

Figure 1. RoboCup competitions. (a) Humanoid robot Nao used in RoboCup's Standard Platform League. (b) Presentation at RoboCup Junior Dance Competition.

robotic soccer as a challenging application domain and as a benchmark for such autonomous intelligent systems. This led to regular competitions of the Robot Soccer World Cup, or RoboCup for short. In 2015, RoboCup had its 19th edition, and over 2000 participants from more than 30 different countries gathered in Hefei, China, 19–23 July. In 12 different leagues world champion titles were awarded; five for soccer competitions with different types of robots ranging from wheeled to humanoid, two for search-and-rescue operations, one for domestic service robotic applications, one for logistics and three for the Junior competitions. The intriguing and ambitious long-term vision of RoboCup is: 'By the year 2050, develop a team of fully autonomous humanoid robots that can win against the human soccer world champion.' Regardless of whether this mission seems a bit optimistic, the whole initiative has had an impact on research and education, both at school and university levels. This is evidenced by the fact that each year in the RoboCup symposium proceedings more than 30 scientific articles are published.

The scope of the RoboCup initiative has broadened substantially since its introduction in 1997. Apart from making agents and robots play soccer, there are also competitions in rescue scenarios and domestic service robotics settings as well as in industry automation and logistics. In RoboCup Rescue,[16] the central task is disaster response. The effort features real robots as well as simulation projects. In the real robot project, physical robots have to assist first responders in disaster areas in finding and rescuing humans. In the simulation project, either virtual robots or simulated agents need to perform varying tasks in emergency response. The challenges encompass many topics, ranging from mechatronics to singe-agent and robot behaviour to multi-agent coordination. In RoboCup@Home,[17] the application domain is domestic service robotics. The competition is used to benchmark and foster the development of socially assistive robot technology.[18] While in the soccer leagues the complexity of the task lies in quickly accessing the sensors, rapid decision-making and cooperation, the challenge in the @Home league is to build a system which enables a robot to safely navigate through and to robustly operate in human-populated home environments. Since the league focuses on service robotics applications, a vital aspect is that of natural human–robot interaction. The RoboCup Logistics League focuses on in-factory logistics and what is nowadays referred to as Industry 4.0. The goal is to foster research in and to produce flexible solutions for organising the material and information flow in an automated industrial production scenario. Teams of autonomous robots compete in producing goods in an automated factory where orders come in and need to be addressed dynamically. Besides tasks like navigation and limited manipulation, the crucial challenges include scheduling and planning

Since 2000 RoboCup has also reached out to students below university level with the RoboCup Junior activities. The idea is to interest learners of up to 19 years of age in research and technology in a playful way. RoboCup Junior aims 'to create a learning environment for today, and to foster understanding among humans and technology for tomorrow.' The concept of RoboCup Junior is to use state-of-the-art teaching material, make students work in teams, and to support international exposure, exchange and contacts. RoboCup Junior includes three different leagues: (1) dance, (2) soccer and (3) rescue. Competitions are held in two age groups: in the primary group, learners are aged up to 14 years; the secondary group consists of participants who are 14 years of age and above. Figure 1(b) shows a performance of the RoboCup Junior Dance League, which is particularly attractive for girls. In the dance competition the robots perform a show act, sometimes together with their programmers. In the RoboCup Junior Soccer League, two teams of two robots play soccer against each other with an infrared-light emitting soccer ball. This simplification allows learners with less technical experience and with less funding for robots with vision systems to participate.

Finally, there is the Rescue League with its very palpable mission goals. In an indoor disaster site, the robot needs to find a way through the different rooms on the first floor to reach a ramp that leads to the second floor. Here, the robot has to find casualties making its way through debris. Besides the exposure to cutting-edge technology, the learners participating in RoboCup Junior come into contact with senior researchers and university students at international competitions. This way, the tertiary education system becomes much less abstract for the students.

Involvement in RoboCup teams

In this section, we describe the RoboCup activities and teams we have been involved with from both Germany and South Africa, focusing on north–south collaboration aspects. Some of the authors have more than 10 years' experience in RoboCup competitions and were active in a number of different leagues. The authors have entered RoboCup competitions in the Simulation League, the Middle-Size League, the Standard Platform League, in RoboCup@Home, the Rescue League and the Logistics League. The soccer team 'AllemaniACs', the service robot team 'AllemaniACs@Home' and the logistics robot team 'Carologistics' were run solely by the German partners, while the team in the Rescue League 'UCT Ratel' as well as the small-size soccer teams 'UCT SSL' and 'UKZN SSL' were run by the South African partners. Team 'ZaDeAt' which competed in the Standard Platform League was a joint venture between the German and South African partners (together with Austrian colleagues). Likewise, the 'UCT Junior' engagement was started as a joint venture between the three parties, but was then organised and conducted by the South African colleagues. This means that there is experience in running RoboCup teams on both sides; moreover, the South African and German partners also collaborated intensively on a number of RoboCup activities. A concise overview of the different projects is given in Table 1 which also shows interesting figures such as the success of the efforts (in terms of publications and theses) and funding. An overview of the general robotics landscape in South Africa can be found in Utete et al.[12]

Participation in soccer leagues

AllemaniACs Soccer. The AllemaniACs Mid-Size RoboCup team was founded in 2001 at the Knowledge-Based Systems Group (KBSG) at RWTH Aachen University. The KBSG participated in a large-scale Priority Programme (`http://gepris.dfg.de/gepris/projekt/5471357?language=en`) funded by the German National Science Foundation (DFG). The RoboCup activities were the show-case and the demonstrator of research results on *logic-based high-level control for embodied agents in dynamic real-time domains* that came out of the DFG project. Initially, two PhD students and two student

Table 1. Overview of RoboCup teams of authors.

Project (Country)[a]	Description/Research focus	Best result (ranking/no. of teams)	Average team size	Theses	Research articles	Run time	Main funding	Estimated Budget: Total	Estimated Budget: p.a.
AllemaniACs Soccer (DE)	Logic-based high-level control for soccer robots	RC: 7/24 (2005)	5	PhD: 1, MSc: 13	17	2001–2011	DFG	625,000	62,500
AllemaniACs @Home (DE)	Domestic service robotics	RC: 1/10 (2006) 1/20 (2007) GO: 1/5 (2007, 2008)	3–4	PhD: 1, MSc: 6 BSc: 1	17+6	2006–2012	Institutional +Sponsors	300,000	50,000
Carologistics (DE)	Smart factory automation	RC: 1/8 (2014, 2015), GO: 1/6 (2014, 2015)	10	BSc: 3	7	2012–today	Institutional	2000,000	50,000
ZaDeAt (Za/DE/AT)	Controlling standardized humanoids	RC: 9/24 (2009)	6	MSc: 3	3	2008–2010	BMBF	37,000	12,333
UCT Ratel (ZA)	Rescue robot development	RC: 13 (2012)	6	MSc: 8	2	2008–2013	Institutional	70,000	11,600
UCT Soccer SSL (ZA)	Team of small soccer robots	N/A	N/A	MSc: 1	1	2008–2012	DST	158,000	39,500
UKZN Soccer SSL (ZA)	Team of small soccer robots	N/A	10	MSc: 1 BSc: 4	2	2008–2012	DST	157,980	39,495
UCT Junior (ZA)	Teaching learners the concept for robot programming	RCL 22/51 (2010)	7	N/A	1	2009–2010	Sponsors	15,000	15,000

[a]ZA=South Africa, AT=Austria, DE=Germany.

workers were funded for a period of two years. After a review at the end of the first funding period, we were successful in acquiring funding for one PhD student and two student workers for two subsequent periods, each lasting two years. The overall project funding was spread from the planned six years of the programme to a total of 10 years project run-time. Some of the remaining funds were only spent at the beginning of 2011. As it is quite hard to calculate the direct related cost of the RoboCup team, in Table 1 a lump sum of funds that went into the team was estimated (first row, *AllemaniACs Soccer*). This includes the staff costs, hardware costs and travel expenses. The educational and research success of this project can be substantiated with 17 research articles, one PhD thesis and 13 master's theses. In terms of rankings at competitions, the team was not that successful. However, the foundation was laid for the AllemaniACs@Home team, the ZaDeAt team and the Carologistics RoboCup team. We further built fundamental (theoretical and practical) knowledge in how to build and control an intelligent autonomous mobile robot system. This was key in future successes with our follow-up RoboCup teams.

ZaDeAt. Team ZaDeAt was an effort between UCT, South Africa, RWTH Aachen University, Germany, and Graz University of Technology, Austria, to establish a RoboCup team for the Standard Platform League. We entered this league when the Aldebaran Nao superseded the Sony Aibo as the standard platform. This way, the entry barrier for a new team was a bit lower. The research interests of the different groups were on the high-level side, comprising the fields of reasoning about actions, model-based diagnosis and reconfiguration, and emergent behaviour modelling. The aim was to integrate ideas from these fields, which, by then, were developed largely independently from each other, into a single system. With funding by the International Bureau of the German Ministry of Science and Education (IB BMBF) and a grant by the South African Department of Science and Technology (DST), the team was able to participate three times at RoboCup competitions and ranked in the midfield to lower half among the competitors. The scientific output was three conference publications and two master's theses. The project was not supported by a PhD student. Therefore, the budgets in Table 1 (row 4) reflect mainly hardware costs and travel expenses.

The DST SSL initiative. From 2005 onwards, the Robots and Agents Research Lab (RARL) at UCT began work on a team of robots that was to participate in the RoboCup's SSL. In 2011, a project was started that would attempt to produce the first fully functional team of SSL robots. The project was funded by a research programme of the South African DST together with three other universities. The project included the development of the locomotion system, the ball handling system, the control and communication system and the power system. The development was fairly successful and resulted in a robot that could drive around the field and manipulate the ball. The hardware system was fully functional, however, the lack of a high-level control system and any follow-up projects meant the robots never participated in any RoboCup competition. One of the developed robots is shown in Figure 3(d). Another team involved with the RoboCup SSL initiative funded by the South African DST was at the University of KwaZulu-Natal (UKZN). The project was pursued by a group of honour-level students and postgraduate students. They had to develop a mechanical design, integrate it with the electronic and computer system and perform the necessary requirements for the competition. These robots never competed in any RoboCup competition. However, the robots were used after the initiative for an MSc student to research swarm networking between robots. This allowed for two conference articles to be published.

Participation in non-soccer leagues

AllemaniACs@Home. When the RoboCup@Home competition was introduced in 2006, the AllemaniACs formed a team to participate in this new league. Being able to build on a large set of existing technology, we won the competition in its first and second years. This was, firstly, largely due to the experience in RoboCup from the mid-size effort. Secondly, the AllemaniACs never focused solely on the soccer competition. Instead, the solutions were always created to be open to other (office robotics) applications as well. Figure 3(a) shows the domestic robot Caesar. It is important to mention that the AllemaniACs' endeavour in the @Home league had no separate funding. Instead, it was co-financed by other (robotics) research projects of the KBSG. Further, some money was received from sponsors to cover travel expenses (especially for RoboCup in the US and in China). The domestic service robotics scenario served as a benchmark and an application domain for the research conducted by the group. Team members took an active part in technical committees to further develop this domestic service robot benchmark. The success of the project is remarkable in many respects. We won the world championship in 2006 and 2007 and we won the RoboCup German Open in 2007 and 2008 as well. In 2008 we came in second at RoboCup and ranked shared sixth in 2009. After 2009 we did not participate in any tournament for lack of a constant work force. However, we continued to conduct and evaluate research in the scope of RoboCup@Home. A total of 23 academic articles have been published as a result of the work in @Home. One PhD thesis, six master's theses and one Bachelor's thesis were successfully completed within the scope of the AllemaniACs' commitment in the @Home league. The robot was used not only for the competition but also served in teaching activities of the KBSG. As an example, students used the robot in a lab course to create an interactive game where humans play with robots. Another important lesson learnt was that sustainable team structures are needed to be able to participate successfully in such competitions.

Carologistics. Founded in 2012, the Carologistics RoboCup Team (`http://carologistics.org/`) is the latest RoboCup team from Aachen. It is a joint venture between the KBSG, the Institute Cluster IMA/ZLW & IfU (both RWTH Aachen University) and the Mobile Autonomous Systems & Cognitive Robotics Institute at FH Aachen University of Applied Sciences. The RoboCup Logistics League (`http://robocup-logistics.org/`) is a new league focusing on mobile autonomous robots in a factory floor environment. While no funded research project is connected to this project, the participating institutions are financing it. Hence, no staff costs are involved in the lump sum of Table 1 (row 3). The costs include mainly hardware and travel costs. The structure of this team is, in particular, interesting. The team leaders from the different institutions all have long-standing experience with RoboCup teams and very successfully passed on their knowledge of how to run a RoboCup team, and also how to program an intelligent high-level robot, to the new student members of the team. Despite this head start, it took two years to be successful in the competition. A noteworthy fact about the Carologistics team is that the team leaders are very actively involved in developing the league into an interesting research scenario. Members of the team play an active role as league executives, technical and organisation committee members of this league. The research output of 15 research articles and three Bachelor's theses is quite impressive for the short amount of time the team has existed.

Ratel. UCT began developing the Ratel (see Figure 3(c)) as an unmanned ground vehicle in 2008. The RoboCup Rescue competition was an ideal research focus for development and testing of such robots in simulated disaster conditions. The Ratel was developed as a multi-purpose unmanned ground vehicle which was to be evaluated according to the challenges of the RoboCup Rescue competition.[19] It was designed with a six-degree-of-freedom arm, a gripper and various sensors, some of which were an Asus Xtion PRO, a laser scanner, a thermal camera and a carbon dioxide sensor. Locomotion was achieved via independently driven tracks and both front and rear flippers were present to allow it to surmount obstacles. In 2012, a team of students went to Mexico to participate in the RoboCup Rescue competition. This was the first time the Ratel was to be tested in a competition environment and the first time the research group participated in a RoboCup Rescue competition. Many challenges were present in getting to this point including the great expense of travel and the expense and delay of getting the robot into Mexico. The team placed last in the competition. Eight master's-level projects were produced from the development of the robot and the costs in Table 1 are estimates of student, hardware and travel costs. Since the competition, the research focus has shifted from the larger, more complex and expensive rescue robots to smaller, simpler and more cost-effective ones.[20]

Participation in RoboCup Junior: The team AmaJukuJuku

In February 2010, together with colleagues from the University of Graz, members of the RARL at UCT started the South African RoboCup Junior initiative. We invited ninth-grade learners from six different Cape Town schools (disadvantaged and privileged) to participate in our Cape Town RoboCup Junior Challenge. In a series of seminars, the learners were introduced to the very basics of robotics and the Lego Mindstorm NXT platform as well as the RoboCup Junior Rescue competition rules. At the end of two weeks of seminars, all teams competed in a rule-compliant competition. The most promising one was selected to participate in the RoboCup competition in Singapore. For training sessions, the learners had to be collected from within a perimeter of about 60 km and had to be driven to the lab. In Figure 2a the whole learner group participating in the UCT challenge is shown, Figure 2b shows the team that went to Singapore. Some of the things that also had to be taken care of from the lab's side were applications for passports and visas, and included even simple things such as providing suitcases for the learners, as in most cases their parents were not financially able to contribute. The result at the RoboCup in Singapore was a considerable seventh place out of 51 participants in the second round. At the end of the competition, the team was ranked position 22, which, considering that the preparation time for the team was rather short and they had only had access to the robots for a few hours a week, is a very respectable result. From interviews with the participants we learnt that this was quite an experience for the mostly disadvantaged learners who had never left the country before. As a side product of this effort, the learners were much more confident in their own skills. Asked in interviews, they longed for skilled jobs, wanting to become doctors or engineers.

Performance in RoboCup and lessons learnt

As can be seen from Table 1, participating in RoboCup comes with significant costs. A number of students and/ or staff have to program and build the robots, the hardware is quite expensive, there are travel costs when participating in competitions, and so on. The question is why one should participate in RoboCup at all. Is it really worth the effort? In 'Project reviews and lessons learnt' we critically review the outcomes of the different RoboCup projects mentioned based on the indicators presented in 'Performance indicators' and give an overview of the lessons learnt.

Performance indicators

In the following we distinguish primary (or hard) indicators which can be used to measure the success or failure of the

Figure 2. Team AmaJukuJuku. (a) Learners at the UCT RoboCup Trials. (b) The AmaJukuJuku team in Singapore.

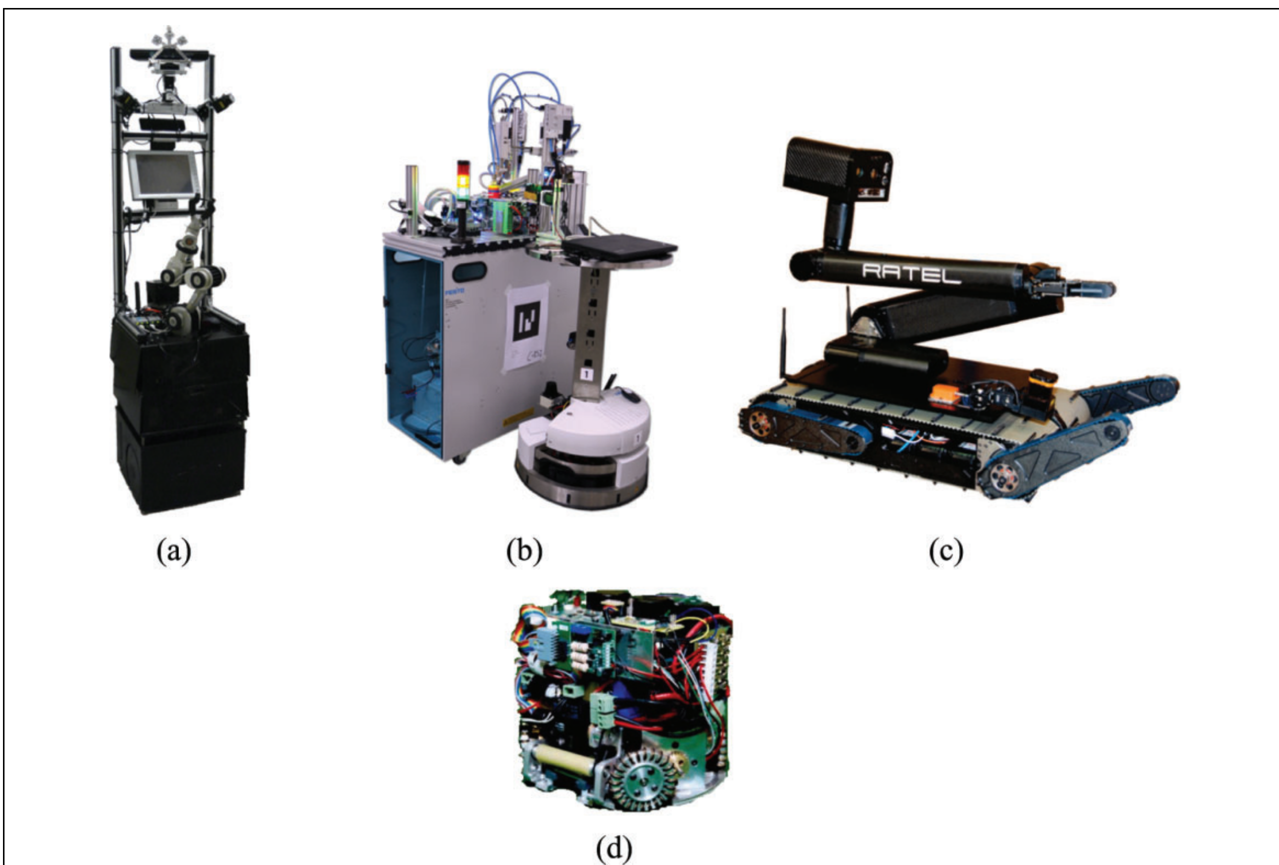

Figure 3. Some of the authors' robots which participated in RoboCup competitions. (a) The AllemaniACs@Home robot Caesar. (b) A Robotino from team Carologistics. (c) UCT's Ratel. (d) UCT's SSL Robot.

conducted projects. But besides these hard facts, there are also a number of secondary (or soft) indicators. These highlight the benefits for students who participate in a RoboCup team and are based on our teaching experience (rather than on provable facts).

The success of a RoboCup participation can be measured by the following primary indicators.

Number of research articles. The number of research articles is, in particular, important as it shows that the outcome is not only on the educational side. Further, it shows the importance of the project to the funding agencies. A factor of similar importance is the number of theses that were written in the context of the RoboCup team.

Ranking in competitions. The ranking in competitions is not necessarily a good indicator of research outcomes. Many problems that have to be solved by a RoboCup team are practical ones: making things work on time. Often, rather robust approaches which are known to work will be used instead of sophisticated, maybe not quite mature methods. In spite of this, many RoboCup leagues offer an interesting testbed for scientific approaches in the field of mobile robots. What a good ranking does show, however, is that the RoboCup team is well organised and able to produce running solutions in the competition.

Participation in competitions and committees. It can be observed that new RoboCup teams need at least one year of experience at competitions to learn what organisational aspects besides the technical solution need to be focused on. It is also important to have a good mix between new and experienced team members in the team. This also implies that successful RoboCup participation is not a one-shot event. One has to participate for several years in a row. This also has to do with the rules which change from year to year. The latter aspect can also be taken as another indicator of successful participation. If team members get involved in the league committees, they show interest in determining future directions for that particular RoboCup league.

Budget. An important indicator is, of course, the budget. To travel with a team of five to ten students and staff and robots, tools and hardware to a RoboCup competition overseas will cost a large amount of money. Building a robot is also an expensive endeavour. Consequently, less funding makes it harder to participate. However, enough funding does not mean that you will be successful at a RoboCup competition. The other indicators such as expertise and a sustainable team structure are probably of similar importance.

Participating students learn valuable lessons stated in the following secondary indicators. These are, inter alia, the following.

Project-based approach. Team work in general is an important experience for future work life, where project-based work is the norm. RoboCup teams offer a kind of dry-run to gain experience with the up-sides as well as with the downsides of a team where everybody relies on each other.

Meeting hard deadlines. Another important lesson that students learn is that their share of work matters in bringing the team forward and what it means if others are relying on one's piece of work. If some parts of the system are not ready on time, the whole team is often in trouble. When the game is on, there is no chance to get extra time to finish one's own work package.

Usage of state-of-the-art development tools. In addition, the students usually have access to state-of-the-art hardware used in mobile robotics. As for the software development process, the students are exposed to state-of-the-art development tools which is beneficial for their future careers.

International exposure. Being involved in an international research community at the competitions and getting to know a lively research community at RoboCup competitions broadens the students' perspective and gives insight into some research communities. This adds to their perception of academia which mostly is seen just from the student's side of sitting exams and studying at the library.

Hence, even if the team was not very successful in the competition, the participating students learn many things which are valuable for their future careers and are not necessarily taught at universities.

Project reviews and lessons learnt

German projects. The three projects from the German partners (AllemaniACs and Carologistics) can be regarded as successful. The teams won the RoboCup championships twice in the @Home league and twice in the RoboCup Logistics League. Also, the number of theses and research articles produced is quite high. On the other hand, the project funding shown in Table 1 also exceeds the funding of the other projects compared. The success of the teams AllemaniACs@Home and Carologistics can be explained by the long engagement in the AllemaniACs Soccer project. Over a long time stretch of nearly 10 years students and staff could gather a lot of experience in how to program and design robots and participate in such competitions. The very same staff took leading roles in running the other projects. This means that the good results would not have been possible without the soccer project where all the experience was gathered. A key for the success was that there was continuity in the development of the robot hardware and software as well as in the deployment of staff. Additionally, there were always some PhD students responsible for the project who were driving the development. This was of particular importance to ensure sustainable development in hardware, software and human resources.

Joint projects. The ZaDeAt project was a joint venture between South Africa, Germany and Austria. The overall funding was to cover the hardware cost of three Nao robots and travel expenses between the partners. The output of three master's theses is reasonable given the restricted funding. Part of the funding scheme was to participate in RoboCup tournaments. The outcome of the project was not overwhelming, but the teams participated in three RoboCup tournaments and exposed the students to the international RoboCup competitions. Even though the partners had experience with RoboCup, the main problem in this project, namely the large distance between the project partners which stood in the way of continuous development of the control software, could not be overcome. Nonetheless, the students involved learnt valuable lessons along the mentioned secondary indicators.

South African projects. The Ratel project, which was a fully South African venture, suffered from a number of challenges. A very complex and impressive system was created from scratch by many different students. However, there was a lack of time to fully test and validate the system before the 2012 RoboCup. This led to many issues cropping up at the competition. Waiting till the following RoboCup was not feasible as the lack of continuity of students would lead to an untrained team running work done by others. Lack of funding and space meant that no test arena could be built and so many tests could not be completed. The cost to ship both the team and the robot to Mexico was immense and the robot was damaged by inspectors when it reached Mexico. Although the team placed last in the competition, many lessons were learnt about software systems used such as ROS and how the competition was run. It was also valuable to have exposure to and understand other universities' techniques, software and hardware approaches. After Mexico, it was felt that redesigning the software to become RoboCup-compatible and ironing out the hardware bugs would require too much funding and that a new set of students would require too much time to be brought up to date. The project was abandoned in favour of a new, smaller and simpler rescue robot which is still in development. If more collaboration between different universities and faculties within the same university was possible and the workload and funding required was being shared, the project might have continued. The project provided experience and degrees to many master's students in many new research fields and a number of published conference articles.

The UKZN SSL robots were developed by postgraduate students. The mechanical structure and the electronics with the local AI were developed. The local AI consisted of the control system, identifying the ball for dribbling, and performing the appropriate instructions it would receive from the global AI system, which was not completed. The UCT SSL robots were mostly completed mechanically and electrically with some electrical components being provided to other South African teams. However, the AI was never completed. Neither of the teams from the South African SSL initiative ended up going to a RoboCup competition. The reasons for this include a lack of cooperation between different universities and departments within universities. Another problem was that the minimal funds that were made available were only confirmed and made available approximately five months into the year. With the South African academic year starting in January, this resulted in students not being assigned to the project, as there were no overdraft facilities available to start the project. Since the funds became available so late in the year, and there was a need to meet deadlines by November (i.e. there were five months to work on the project), the result was that the postgraduate students had to work on this project as a side-line project. The same issue applied to the undergraduate students working on the project.

Although no team participated in a RoboCup competition the initiative should not be considered a failure. Both projects resulted in the graduation of MSc students and led to published articles. The hardware still exists today and remains an interesting learning vehicle for studies into other forms of RoboCup. Even though there were logistics-related problems that were experienced with the politics between different institutions, there were a few undergraduate and postgraduate students that were able to learn engineering skills in disciplines other than those they were trained in, and the project coordinators could discover problems which were experienced at a logistical level. Finally, a postgraduate student pursued using the robots to develop a swarming network. At this stage, research articles have been published using these platforms. Another lesson learnt was that a small research group should not take on more than one RoboCup league, and should rather focus on one until experience has been gained.

On a final note, we want to mention the RoboCup Junior effort that took place in 2010. The greatest achievement of this project besides bringing learners with disadvantaged backgrounds (due to the aftermath of apartheid) to program robots was to secure funding for the trip to Singapore. The problems were having to take care of several issues, from organising the trips to the training venue in South Africa, to organising passports, to even providing suitcases: things you would take for granted in developed countries. With the help of local sponsors, it was possible to raise enough funds to participate in the RoboCup Junior competition in 2010, which was a once-in-a-lifetime experience for the learners. Unfortunately, it was not possible to establish RoboCup Junior trials, mainly because of a lack of ongoing funding. We reported our efforts in Ferrein et al.[9]

General lessons learnt. One of the main lessons we learnt from our RoboCup activities was to keep and pass on the working knowledge from one generation of students to the next. This step was much easier if the project was linked to some research project where a PhD student took the lead and organised the student teams. Of course, the project funding is an important part of the success of a RoboCup activity, but funding alone will not guarantee success. The passion of the participants is very important. To sustain such an activity, it helps if the knowledge transfer (on each possible level) is organised through a dedicated team leader (e.g. a funded PhD student) who sticks to the project for an extended period of time. The criteria for labelling a RoboCup team effort a success range from the research output to rankings in the competition to participating in committees.

Table 2. Comparison of some relevant indicators.

	State Expenditure (% GDP in 2010)		School Enrolment (% gross in 2012/2013)			Highest Educational Level[a] (% gross in 2014)			Number of Universities/Enrolled Students (in millions)	Researchers[b] (per million people in 2008)
	Educational[c]	Research[d]	PRM[e]	SEC[f]	TER[g]	LSEC	HSEC	TER		
Germany	5.1 (rank 74)	2.80	100	101	60	10	50	28	415[h]/2.4	3700
South Africa	6.0 (rank 42)	0.76	101	110	20	14	47	6	23[i]/0.8	395
Brazil	5.8 (rank 49)	1.15	N/A	N/A	N/A	15	32	13	2391/7.3	696

[a]http://www.datenportal.bmbf.de/portal/de/Tabelle-0.23.html.
[b]http://www.tradingeconomics.com/germany/researchers-in-r-d-per-million-people-wb-data.html, http://www.tradingeconomics.com/south-africa/researchers-in-r-d-per-million-people-wb-data.html, http://www.tradingeconomics.com/brazil/researchers-in-r-d-per-million-people-wb-data.html.
[c]https://www.cia.gov/library/publications/the-world-factbook/rankorder/2206rank.html.
[d]http://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS.
[e]http://data.worldbank.org/indicator/SE.PRM.ENRR/countries.
[f]http://data.worldbank.org/indicator/SE.SEC.ENRR/countries.
[g]http://data.worldbank.org/indicator/SE.TER.ENRR/countries.
[h]http://www.bmbf.de/en/655.php.
[i]http://ufisa.aalto.fi/en/network/cput/facts_figures_section.pdf.

Conclusions: Why we think it is harder to set up RoboCup in South Africa

In this section we want to analyse why the endeavour of the authors to establish RoboCup in South Africa has not (yet) been successful and why RoboCup did not take off in South Africa.

Main reasons

Lack of local community. Just before the FIFA World Cup in 2010, which was hosted by an African nation for the first time ever, there was an effort by local scientific organisations with support from some of the authors to host the RoboCup competition in South Africa. Usually, RoboCup is held in the same country as the FIFA World Cup. Despite a local effort to host the event, it was given to Singapore in 2010. One of the main reasons for not giving the event to South Africa was that there was no active RoboCup community in South Africa. Maybe the whole idea to bring RoboCup to South Africa with external researchers was doomed to fail and if some local teams existed, there would have been a better chance. Even with government-provided funding to start some teams in South Africa, the teams never participated in international championships.

National education expenditure and number of research staff. Surely, the national education expenditure plays an important role. Germany spends a smaller percentage of their GDP on the education sector than South Africa does, but more of the money goes into research (columns two and three in Table 2). Looking at absolute figures, one has to bear in mind, however, that Germany's GDP is about 5.5 times larger than that of South Africa. The number of researchers per million people (last column in Table 2) shows that there are nearly 10 times as many academics in Germany. This correlates with the percentage of the population which holds a university degree (ninth column in the table). This simply means that with more academics around there are more chances to find researchers who are interested in RoboCup as an education and research vehicle. But this cannot be the only reason. If we compare the same figures with Brazil as another BRICS (Brazil, Russia, India, China, South Africa) state, they are in the range of South Africa. However, Brazil has a very lively RoboCup community. In Figure 4 we show the number of German and Brazilian teams at RoboCup competitions. In spite of similar expenditures, Brazil is participating on a regular basis in international RoboCup competitions.

Access to students. Comparing the number of universities and students per university, it becomes clear that South Africa has some disadvantages (column 10 in Table 2). South Africa has a comparably small number of universities; each university hosts 35,000 students on average. Even when removing the largest non-presence university UNISA, which hosts about 260,000 students, from the calculation there are, on average, 25,000 students enrolled at each university in South Africa. The numbers for Germany and Brazil are about 5800 and about 3000. As a consequence, there are more students per teacher in South African universities and therefore there is also less time to engage with such extra-curricular activities as RoboCup. As another problem, many students take positions in industry after their Bachelor's degree and are not available for extra activities in their academic life.

Academic eco-system. Most of the performance rating for South African academics is driven by ISI-rated

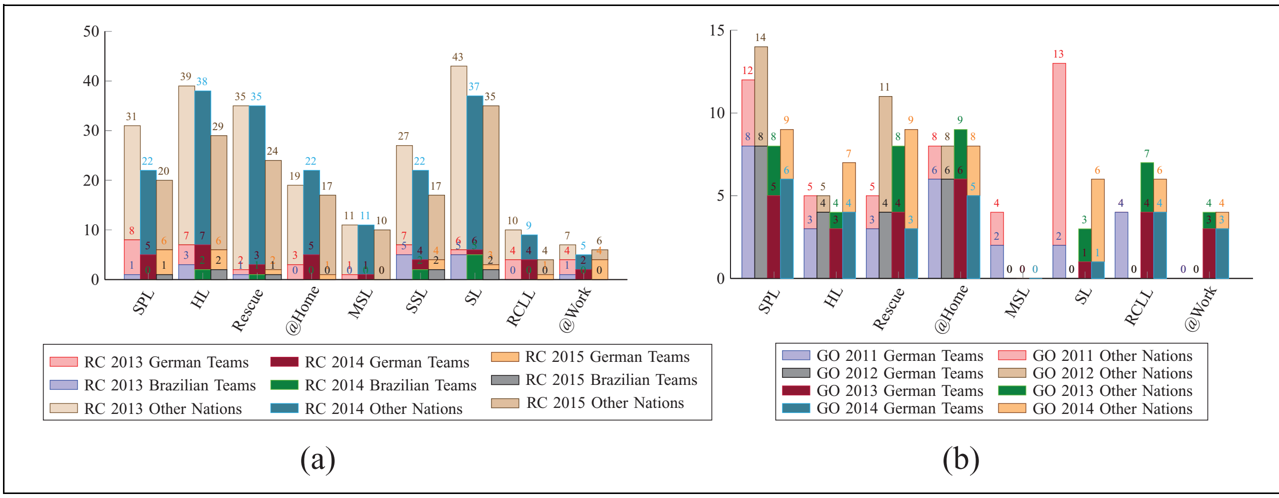

Figure 4. Breakdown of RoboCup participation for Germany, Brazil and other nations. RC stands for RoboCup (the world championships) and GO stands for German Open (which in fact are the European open championships). (a) Teams at RoboCup 2013, 2014 and 2015. (b) Teams at German Open 2011–2014.

publications[a]. The expectations at some universities are to publish three to five journal articles per year, even for young academics. This imposes high pressure on the academics leaving less room for extra-curricular activities that might not directly and immediately lead to research articles. This problem also leads to some lack of will in cooperating in projects such as building up a RoboCup team. While there is also pressure on German academics to publish articles, in our experience good results in RoboCup are valued nonetheless. Furthermore, the lack of collaboration is a major factor experienced in South Africa. The different research institutions do not want to collaborate as there is the argument of who the intellectual property belongs to. Additionally, due to a much smaller total number of academics, many want to stick closely to their field of expertise, which affects the will to spend time on projects such as supporting students in a RoboCup team.

Funding situation. While public funding is made available in South Africa by the National Research Foundation, it is on a smaller scale than in Germany. Activities such as RoboCup often need to be funded through basic university funding. South African universities obtain funds from the government when ISI publications are obtained from the research conducted; this reason motivates universities to justify whether or not research should continue. The output and thus the income to universities is the driving factor that the institutions consider, even if the RoboCup projects might become a marketing tool to attract students and further funding. For a German researcher it is easier to acquire funding than for their South African counterpart. There are state funding, national funding (DFG, German Federal Ministry of Science and Education) and also European research programmes. Of course, acquiring funds is also very competitive in Germany, however, looking at the figures reveals that there is success across all disciplines. According to an Internet statistic source (`http://de.statista.com/statistik/daten/studie/169069/umfrage/drittmittel-einnahmen-hochschulen-1998-und-2008/`) an additional €7b was acquired by universities through third-party funds (DFG, BMBF, industry, EU and others) in 2013.

Being far away. 'Being far away' comes with the requirement to always travel overseas in order to attend RoboCup competitions. This adds to the already high overall cost of maintaining a RoboCup team. One could argue that Brazil is in a similar situation. This is indeed reflected in our figures. In Figure 4(a) we see up to one or two Brazilian teams participating per league. In 2014, however, these numbers were much higher, because Brazil hosted RoboCup in 2014. The reason is that Brazil is dealing with the problem by organising a local RoboCup community with local competitions. The situation in Germany is again different. The number of German teams is over-proportional; this can also be seen in Figure 4(b), where the German teams which participate in the German Open are presented. In many leagues half of the teams participating in the league are from Germany. This said, one has to understand that the German Opens are European Open championships rather than a local German competition.

Early development. South Africa has a large portion of its population attending secondary-level schools that are undeveloped. The basic infrastructure for schooling is not available, and many scholars have the problem of not obtaining a nutritional meal during the day. It has been seen even at a university student level that the scholarships that have been obtained are used to sustain the student's family. With this picture in mind, there is a lack of robotics education in the secondary-level education system. Some community service work has been conducted with some schools to promote robotics, yet the expense of robotic systems such as the Lego Mindstorms EV3, Thymio or similar educational robotics systems has prevented both the scholars and the schools from obtaining these kits themselves. The one advantage that South African students have is the ability to think outside the box to solve problems in robotics. This is because they have not had the privilege of having everything made available to them. Thus, they have had the need to find alternative and cheaper solutions, and often perform well due to their innovative skills. Even with the large learning curve required, the evolution of robotics within South Africa could be more competitive at a competition level, if scholars are prepared earlier with events such as RoboCupJunior. If these events could be arranged so that the robotics systems which are used are low-cost systems (possibly using recycled products), this would allow for a fair competition that every school and scholar could participate in if they wished to enter and would increase the general skill level of learners as well as the interest in robotics

Outlook. RoboCup is indeed an interesting and valuable education initiative. In the robotics community, there is a debate as to whether or not 'serious research' is being conducted within RoboCup. Hundreds of research articles published by renowned journals and international conferences show that serious research output is generated by RoboCup participants. Even for extreme sceptics it must be apparent that RoboCup provides a challenging testbed for robotics and AI research, in particular with the application leagues (rescue, @home, logistics). Besides RoboCup being a successful initiative, participating in RoboCup is challenging from the financial side. It is quite costly to send five to ten students overseas and to build and maintain competitive robots. To acquire the needed amount of money, one has to find sponsors or be somewhat creative, as research agencies usually do not support going to a robotic competition. One possible way to overcome this is to use RoboCup as a benchmark for other research activities. Trying to establish RoboCup Junior also was not very successful and after one participation in 2010, it was not possible to sustain this activity due to funding and staff issues.

Based on our experiences with RoboCup teams in Germany and South Africa, we have discussed several reasons why it is harder to establish an engaged RoboCup community in South Africa than in Germany or Brazil. This is, of course, not a unique South African problem, but it adds to the difficult situation. Despite the outlined challenges in establishing RoboCup in South Africa, believing in the strength of the initiative, we will continue advertising it in South Africa, and Africa in general. Recent African roboticists networks such as AFRON (http://robotics-africa.org/) or the Developing World Robotics forum (http://developingworldrobotics.org/) might play an important role in helping spread the RoboCup initiative or similar initiatives in sub-Saharan Africa to support the education of the very important emerging field of robotics.

Lastly, a means of overcoming the collaboration restrictions within South Africa needs to be developed. A South African Robotics Centre has been established which is supported by the South African Institution for Electrical Engineers. The initiative is aimed at getting universities performing research in the area of robotics to come to an agreement of working together to improve robotics research within the country, rather than competing against each other. The centre was initiated in 2015 and established in 2016. The progression of the centre and the impact that it has will only be seen in future, yet since this recent initiative some positive robotic initiatives have already developed which involved our collaboration.

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Note

a. ISI stands for Institute for Scientific Information; the impact of journals are rated by this institution. It is now also called Thomson Reuters Impact Factor.

References

1. Alimisis D. Educational robotics: Open questions and new challenges. *Theme Sci Tech Ed* 2013; 6: 63–71.
2. Dias MB, Mills-Tettey GA and Nanayakkara DPT. Robotics, education, and sustainable development. In: *Proceedings of the 2005 IEEE international conference on robotics and automation, (ICRA-2005)*, Barcelona, Spain, 18–22 April 2005, pp.4248–4253.
3. Ruiz-del Solar J and Zagal J. How contests can foster the research activities on robotics in developing countries: Chile – a case study. In: Polani D, Browning B, Bonarini A, et al. (eds) *RoboCup 2003: Robot Soccer World Cup VII (Lecture Notes in Computer Science*, vol. 3020). Berlin/Heidelberg: Springer, 2004, pp.748–756.
4. Visser U and Burkhard HD. Robocup: 10 years of achievements and future challenges. *AI Mag* 2007; 28: 115.
5. Verner IM. The value of project-based education in robotics. In: Kitano H (ed.) *RoboCup-97: Robot Soccer World Cup I*

(*Lecture Notes in Computer Science*, vol. 1395). Berlin/Heidelberg: Springer, 1998, pp.231–241.

6. Eguchi A, Hughes N, Stocker M, et al. RoboCupJunior: A decade later. In: Röfer T, Mayer N and Savage J, et al. (eds) *RoboCup 2011: Robot Soccer World Cup XV (Lecture Notes in Computer Science*, vol. 7416). Berlin/Heidelberg: Springer, 2012, pp.63–77.
7. Eguchi A. How to turn competitions into international collaboration through educational robotics: A case of RoboCupJunior dance tournament. In: *Proceedings of the Society for Information Technology & Teacher Education international conference*, San Diego, CA, 29 March 2010, pp.4002–4005.
8. Eguchi A and Almeida L. A proposal for RoboCupJunior in Africa: Promoting educational experience with robotics. In: *AFRICON*, 2013, pp.1–5.
9. Ferrein A, Marais S, Potgieter A, et al. RoboCup Junior: A vehicle for s&t education in Africa? In: *Proceedings of the IEEE Region 8 AFRICON*, 2011.
10. Booysen T, Rieger M and Ferrein A. Towards inexpensive robots for science & technology teaching and education in Africa. In: *Proceedings of the IEEE Region 8 AFRICON*, 2011.
11. Gyebi E, Hanheide M and Cielniak G. Affordable mobile robotic platforms for teaching computer science at African universities. In: *Proceedings of the 6th international conference on robotics in education (RIE-15)*, Yverdon-les-Bains, Switzerland, 20–22 May 2015.
12. Utete S, Green J, Liddiard A, et al. Robotics and automation activities in South Africa [industrial activities]. *IEEE Rob Autom Mag* 2013; 20(3): 16–18.
13. Crevier D. *AI: The tumultuous search for artificial intelligence*. NY: BasicBooks, 1993.
14. Gaskin JE. What ever happened to artificial intelligence? *CIO*, Magazine, CXO Media, http://www.cio.com/article/2435395/innovation/what-ever-happened-to-artificial-intelligence-.html (2008, accessed 18 August 2016).
15. Kitano H, Asada M, Kuniyoshi Y, et al. RoboCup: The robot world cup initiative. In: *Proceedings of the first international conference on autonomous agents (Agents-97)*, Marina del Rey, CA, 05–08 February 1997, pp.340–347, New York: ACM.
16. Kitano H, Tadokoro S, Noda I, et al. RoboCup rescue: Search and rescue in large-scale disasters as a domain for autonomous agents research. In: *Proceedings of the 1999 IEEE international conference on systems, man, and cybernetics (IEEE SMC '99)*, Toyko, Japan, 12–15 October 1999, pp.39–743.
17. Van der Zant T and Wisspeintner T. RoboCup X: A proposal for a new league where RoboCup goes real world. In: Bredenfeld A, Jacoff A, Noda I, et al. (eds) *RoboCup (Lecture Notes in Computer Science*, vol. 4020). New York, NY: Springer, pp.166–172.
18. Wisspeintner T, van der Zant T, Iocchi L, et al. RoboCup@Home: Scientific competition and benchmarking for domestic service robots. *Interact Stud Sp Iss Robot Wild* 2009; 10: 392–426.
19. Dreyer E and Marais S. Development of the RATEL UGV platform. In: *Proceedings of the robotics and mechatronics conference of South Africa*, Pretoria, South Africa, 26–27 November 2012, IEEE.
20. Mathew T, Knox G, Fong W, et al. The design of a rugged, low-cost, man-packable urban search and rescue robotic system. In: *Proceedings of the robotics and mechatronics conference of South Africa*, Cape Town, South Africa, 27–28 November 2014.