Student Competition Teams: Combining Research and Teaching

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Abstract. Teaching and research are the two core tasks of universities. In this paper we show how these two tasks can be combined and synergy effects can be created through building up a student team that participates in international competitions. Furthermore, we share the lessons learned from building up our own team and explain what is necessary to make the team last over decades. Therefore, we focus on the aforementioned synergy effects and discuss the advantages and disadvantages of such a tight coupling between teaching and research.

Keywords: Research and Teaching, Student Teams, Robotic Competitions

1 Introduction

Universities should create new knowledge through research activities and transfer knowledge and methodological capabilities to students. Although it seems like this should go hand in hand and a lot of synergy effects between teaching and research should exist, this is sometimes not as easy as it sounds for several reasons. Let us consider a typical structure of universities that are separated in different faculties, which itself are separated into departments. Our interest lies on departments from technical faculties like computer science, electrical engineering, or mechanical engineering. They are often led by a professor supported by PhD students and post-doctoral employees. Please note, that we expect PhD students to be part of the scientific staff with a Master Degree in a related field of their department. The areas of responsibility for PhD students and post-docs are often separated into three parts: Their own doctoral thesis or habilitation, teaching activities and supporting their professor. Often their thesis and habilitation has the highest priority and the rest is handled with as few effort as possible. Unfortunately, this is contrary to the university aim, we formulated above.

In this paper we show how we mostly solved this dissent and thereby, took our teaching and research activities to a new level. We make it possible that teaching and research is almost identical from a PhD student's perspective and point out the potential synergy effects that can be created. Furthermore, we share our experience of building up and running a student team for 12 years until today.

The remainder of this paper is organized into the following sections. In Section 2 an overview is given to related formats that more or less fit to build up a student team. In Section 3 we share our experience of building up our own student team *Carpe Noctem Cassel* and point out the requirements for running such a team over several years. Sections 4 and 5 show how we empower the students to handle research tasks almost autonomously and how we teach topics relevant for our research to our students. In Section 6 we discuss the advantages and disadvantages of our approach and conclude this work in Section 7.

2 Related Work

There are many different kinds of competitions and events where students can participate and compare their skills and abilities. Most of them seem to be very similar, but not all of them suit for building a longterm student team. In this section, we take a look at the different formats and discuss whether they work well for building up a student team. We summarize our evaluation in Table 1.

Formula Student

The Formula Student format requires a student team to build a racing car and race against other teams at different competitions each year[1]. Focus of Formula Student is to give the students, no matter what their discipline is, practical experience for working in the automotive industry. The number of students and financial support for formula student teams is much bigger compared to our soccer robot team, as the automotive industry is the key industry in Germany. At our university a Formula Student, named *Herkules Racing Team*, exists since 2011. The team is composed of students only and its average size is more than 30 students. This is very remarkable, as the students often stay only for one or two seasons in the team. Furthermore, the competition rules require the teams to rebuild their car every year. Note that a car costs roughly 150.000€. However, the scope of activities of a formula student team is not only building the car, but also public relations, fundraising, financial controlling, and race driving. As a result the Formula Student empowers students to work in the automotive industry, but the research departments that support the teams with their expertise, do not get any benefit out of the support for their research activities.

Carolo Cup

The Carolo Cup is an annual national competition for autonomous RC (radio-controlled) cars [20]. The challenge is to drive through realistic environments and show certain skills like parking, racing, driving in usual road traffic, reacting to

[1] http://www.formulastudent.com [last accessed 22th February 2018]

moving obstacles. The student teams need to build a car on their own and are allowed to improve it over the years. Nevertheless, the teams need to be composed without PhD students, thereby, limiting the participation and potential benefits for research departments. Similar to Formula Student, the focus is on educating students with regards to industry requirements only.

DARPA Challenges

The *Defense Advanced Research Projects Agency (DARPA)* is a research agency of the U.S. military. It poses challenges that are known to be extremely demanding, while it offers a considerable amount of prize money. From 2004 to 2007 the DARPA Grand Challenge [2,3] were hold annually. Its objective was to stimulate the development of autonomous cars.

The Robotics Challenge took place from 2012 to 2015. Its focus was to improve the semi-autonomous operation of robots in environments that are hazardous for human beings [8]. It had a huge impact on research about autonomous robots in general. The participating teams in both challenges did not include students, but were composed of (collectives of) research institutes around the world. Our impression is, that these kind of challenges are not very suitable for building up student teams, for the following reasons. At first the utilized hardware is too costly. Further the injury risk for untrained personnel when operating such hardware is too high. In theory, the students could be trained and supervised accordingly, but in practice, the challenges did not last long enough to build up a student team with undergraduates. This is, because DARPA is interested in giving new technology an extra amount of impetus to actually make a difference compared to state-of-the-art technology and is not interested in sustainably supporting the education of people that build these technologies. Finally, we want to emphasize that two critical ingredients for a successful student team are the team members and its financial support. Participating in a military competition could raise problems in acquiring both of it, for ethical reasons.

RoboCup Middle Size League

In the RoboCup Middle Size League each team has its own kind of modus operandi. Let us give two examples that significantly differ from the way, we run our team. We consider students as well as scientific staff as team members and every team member should be able to generate benefits out of its membership (see Section 3-5). The *Paderkickers* from the University of Paderborn in Germany were a team tightly integrated into the curriculum of the department for *Design of Distributed Embedded Systems* [11]. Dr. Bernd Kleinjohann allowed a project group, including 12 students, to work on the robots of the team for two semesters. The idea was to teach the students all they needed to know about the robots in the first semester and afterwards, let them program the complete team strategy and introduce minor hardware modifications in order to participate at the next competition. Thus, knowledge transfer from one group to the next group was limited and the team's performance at the competitions solely

depended on the students prior knowledge. Having a functioning team of robots as testbed for the work of the scientific staff of the department is clearly a benefit, but the students were not directly engaged in research. In our opinion, this limited the synergy effects between research and teaching.
Another example is given by the team *Tech United* of the Technical University of Eindhoven in the Netherlands [9]. The team includes much more scientific staff than *Carpe Noctem Cassel* which limits the number of students that can actually participate in competitions for cost reasons. Nevertheless, from our point of view synergy effects between research and teaching are present in the team. Furthermore, they have generated a lively alumni network that supports the team's efforts. Former students and scientific staff are welcome to further participate during the weekly team meetings and industrial sponsors are also acquired through this social network. As a result, the team's huge financial resources help to always provide the students with state-of-the-art technology and allow them to build and experiment with prototypes independent of their applicability in competitions.

Other Formats

Finally, there are also other formats like hackathons, hacker spaces, Google Summer of Code and communities around interesting open source projects that could also be suitable for building up student teams [17]. The difference is that the teams do not directly compare with each other. Nevertheless, if such a format creates enough longterm motivation for students to participate, the outcome could also be very fruitful. Another advantage of these formats are the reduced costs for operating such a team compared to the aforementioned competitions.

Format	Cost	Initial Hurdle	Research Relevance	Sustainability
Formula Student	0	+	- -	++
Carolo Cup	+	++	- -	++
DARPA Challenges	- -	- -	++	- -
RoboCup MSL	-	+	+	++
Other	++	++	-	0

Table 1. Valuation Summary of Related Formats (From - - to ++)

3 Building up a Student Team

In this section, we describe the domain of our robotic soccer team *Carpe Noctem Cassel*, how a student team is successfully built in general, and how it is possible to run the team over several years in the university context.

3.1 RoboCup Middle Size League Explained

The RoboCup and its competitions are separated into different leagues like Humanoid League, Rescue League, Standard Platform League, Small Size League, Simulation League, and Middle Size League. *Carpe Noctem Cassel* is a Middle Size League team. To conceive an idea of the dimensions of this league some differences to a normal football match are described here. Since 2009, each team consists of five robots, one goalkeeper and 4 field players. Each robot is about 80 cm high and fits into a square of 50cm x 50cm. The field is 12m wide and 18m long. One match lasts two equal periods of 15 minutes. Depending on the team's hardware, a robot can drive up to 5m/s and can shoot the ball over a distance of 16m. Based on that velocity and shooting range it is obvious that there are ever-changing situations during a RoboCup football match, forcing the robots to quickly adapt their behavior to the situation.

The field of expertise, necessary to run such a team of robots, is very wide and can only be covered by fusing disciplines like computer science, mechanical engineering, and electrical engineering in one team. The human team needs to master image processing techniques for the localization, ball and obstacle recognition of the robots. They need solid knowledge in control engineering for implementing precise movement capabilities. In order to compete with the top teams sophisticated AI and team coordination techniques need to be applied. The list is much longer, but not focus of this paper[2].

In Figure 1 a group picture from the last international tournament in Portugal is shown.

3.2 Foundation Phase

Building up a student team is similar to building up any other team. Nevertheless, in the university context there are certain peculiarities that should be taken into account, as discussed in the following paragraphs.

Our focus is on creating synergy effects between research and teaching. This differs from student teams whose sole purpose is to attract students to a certain discipline or provide the students with practical experience that makes them more attractive for future industrial employers. In contrast to this, the next employer of our students should be a university or research institute itself.

In our opinion, the most significant ingredient for a successful team are the people that form it. In case of a student team, we expect it to be composed of a majority of undergraduate students and some graduate and PhD students. Motivating student groups to spend some of their free time in a student team, although their highest priority is to graduate and finish their dissertation, can be difficult. Moreover, the team's foundation phase demands extra effort from all participants, because the extra effort is often neither accredited with credit points nor is it easy to convince a dissertation advisor that such a team improves

[2] The interested reader may have a look at http://www.uni-kassel.de/eecs/carpe-noctem-cassel/publications.html

Fig. 1. *Carpe Noctem Cassel* at the Portuguese Open 2017

a dissertation's quality or represents an advantage for the department's research activities.

When *Carpe Noctem Cassel* was founded in 2005, the two founding PhD students not only asked their advisor for permission, but also for financial and organizational support. The funding for *Carpe Noctem Cassel* was even more critical, because the team had to build a complete new set of soccer robots, in order to participate in the next RoboCup World Championship. As difficult as it was to finance such an effort, the successful funding exceedingly motivated the team members and let them invest even more of their time. In this case, it even affected the team's naming. All team members were willing to work through the night and on weekends, because the founding gave them the feeling that they work for something that will last. In the beginning of *Carpe Noctem Cassel* these three things, people, funding, and motivation were the key ingredients that within 10 month led to the 7th place out of 32 teams at the RoboCup Championship 2006 in Bremen, Germany.

3.3 Running the Team

After the successful founding and participation at the World Championship the question arised how to move on with *Carpe Noctem Cassel*. The team was excited about their achievements and as the RoboCup Foundation also organizes local events like the RoboCup German Open, the team's next goal was to participate at the German Open the next year. The participation in at least one competition per year turned out to be helpful for the teams motivation on the long run. The *joint goal* to improve their performance from year to year provides a continuous challenge, motivation, and fostered the team spirit at the same time. Apart from having a common goal, the team's motivation also consists of the *benefit that each individual team member* draws from her or his contribution to the development. Although it is nice to be part of a team that achieves good results at international competitions, we experienced that it is very important to make clear the individual benefits for every team member clear. The details of these individual benefits are explained in Section 4, as they are the actual reason, we have in mind for running a student team.

Regarding the organization of *Carpe Noctem Cassel*, its *hierarchy was always very flat*. That lowered the barrier for joining the team and allowed new team members to contribute with their ideas. In the university context, the *personnel fluctuation* for a student team is relatively high, because students graduate and leave the team continuously, while new students join. Here, a low entry hurdle helps to recruit new team members and guarantees a constant team size. Furthermore, flat hierarchies facilitate creative processes by giving new ideas enough room to be tested. We could name some more benefits of a flat hierarchy, but it is also important to note that flat hierarchical structures are vulnerable to slow decision making processes. Therfore, the PhD students of *Carpe Noctem Cassel* were established as team management, have financial control over the team budget, and are involved in all critical decisions, in order to guarantee a certain level of progression.

Finally, there is one last point that is essential for running a student team over several years. As mentioned above, the personnel fluctuation in the university context is relatively high. Therefore, it is even more important to have a steady knowledge transfer from old to new team members. Over the years, the developed robots and software packages get more and more complex and harder to maintain. Thus, for new team members the hurdle rises to comprehend even parts, e.g., motion or image processing, of the whole framework. Often single persons with specific knowledge about certain parts emerge. As useful as their expert knowledge is, as critical it is when they resign. Therefore, it should be every team members responsibility to document or at least transfer its knowledge to younger team members months before their resignation.

Paying attention to all the points above by learning from our mistakes, we were able to run *Carpe Noctem Cassel* from 2005 until today. Note that we are currently the last active RoboCup Middle Size League team in Germany.

4 Bringing Students into Research

In this section, we present how the team explicitly encourages the students to autonomously participate in research and develop working methods suitable for scientific application. We also describe how the student team is involved in the research of the department.

Depending on their field of studies and their personal preferences, the students specialize in different aspects of the robotic soccer topic. It is inevitable that the fields of expertise fluctuate over the years with the changing composition of the team. We intentionally let the differing expertise influence the set of issues that are tackled by the team. In a best practice, we regularly analyze the overall performance that was achieved during a tournament together with all team members, to benefit from the complete range of viewpoints and expertise and make all existing issues visible. Because of the high complexity of the tasks, regarding both soft- and hardware there is always a high number of open issues and possibilities for optimization. When the students recognize an issue by themselves during the analysis, they are often motivated to jump directly into solving the issue. They take responsibility for "their" issue and start to look for solutions on their own. Whenever possible, we actively support these efforts by offering topics for study projects or theses. Thereby students provide a benefit for the team and at the same time make progress in their studies. They also feel more connected to the topic, because the motivation for the project was not just assigned to them, but they identified the problem by themselves. This can be seen as a preparatory exercise in identifying relevant research questions like PhD students need to do.

When a study project or thesis is assigned to improve the performance of the team, the students understand the necessity for proper working methods, namely careful requirement specification, documentation and significant validation. This is because a lot of our students experienced that insufficient documentation of previous works leads to difficulties to maintain code up to the complete uselessness of the regarding thesis for the team. As a result the students are prompted to work in a proper scientific manner. This includes documenting both the decisions made during the design process as well as the function of the elaborated solutions.

We also strengthen the scientific orientation of student contributions by pointing the focus to the work of competing teams. There are two main motives in the RoboCup competition. The obvious motivation is winning in the direct competition. The second motivation results from the regular workshops where competing teams come together. They present their progress to the others and work together on connecting elements. Adopting the solution of other teams and developing them further is not regarded as fraud but as good practice to bring the performance of the league forward. This is also enhanced by the open source character of the league. Therefore, when a team presents a well documented and tested solution, this can result in other teams taking this solution instead of further developing their own. We always encourage the students to scan the affiliated works of the competing teams and objectively compare them. We regard this as a good exercise for later scientific work. It includes the intrinsic motivation to present something new, because insufficient literature research will be pointed out by the other teams at the next workshop. The autonomous work on a robotic soccer issue in the team can thereby be regarded as a safe trial for the later work in a scientific context.

Students, who get involved in the team as described above, happen to be more practiced and suitable for scientific work. We observe this by the increased complexity of theses they can handle and the quality of the results [5,12,18,13,4,14]. After some time, the students are able to directly assist the research of the PhD students, even if it is not directly connected to a topic from the robotic soccer domain. These students are also often recruited as undergraduate research assistants and later pursue a PhD at our department. While the German ratio between engineering graduations and engineering disserations was only 11.1% in 2016 [16], 37% of our graduated former team members received a doctor's degree. Moreover, the following PhD theses shaped and were shaped by our robotic soccer team.

Philip Baer and Roland Reichle, who founded the team in 2005 used the application of robotic soccer to test the algorithms, they were working on for their dissertations. Their research focused on teams of robots or digital agents, so the application was rather fitting [1,10]. Later on Hendrik Skubch and Andreas Witsch wrote their PhD theses completely motivated by the requirements of the robotic soccer domain [15,19]. Still their results apply to any homogenous or heterogenous team of robots and are used for many applications in the department. Others like Dominik Kirchner used the excessive amount of log data produced by the robots during training and tournaments as a testbed for their dissertation [7]. One could say, that distributed robotic applications and thereby the student team became a centerpiece of the department's research over the years.

5 Bringing Research to the Students

In this section we present the affiliated courses, where both students and lecturers benefit from our robotic soccer team.

The exciting and multifaceted topic of robotic soccer and the existence of an active team leads to a higher quality of lectures. The lecturers active in the team gather a holistic viewpoint and real-life experiences in the robotic field. The teaching content becomes both more grounded and more inspiring when the lecturer actively works on all aspects of the presented topic. It also reduces the preparatory effort for the lecturers, when the lectures cover the topics, they are working on. The students benefit from the sound and applicable teaching rather than dealing with abstract and hard to test concepts.

We designed three courses around the topics associated with the robotic team: The lecture *Autonomous Mobile Robots* revolves around all major design aspects of an autonomous robotic system. It starts with sensors and measurements, advances with sensor fusion and feature recognition to autonomous decision making, proceeding over control engineering to actuation. We thereby model the structure of a full MAPE-cycle [6], always taking the soccer robots as an illustrative real example.

The lab course *Cooperating Distributed Robotic Systems* is designed to guide the students through a hands-on development process of an autonomous application on existing robot hardware or in a simulator. The sessions alternate freely between conceptual input, when needed and free coding and testing. The exact functionality and structure of the application is developed together with the students in an informal iterative manner with emphasis on small, but running solutions to keep up the motivation. The lecturer helps out when difficulties occur and presents best practices to proceed in such situations without external help, encouraging the development of independence.

The practical course called *Teamwork* was born out of the observation that our students often lack the experience and the skills for working in teams with heterogeneous study background. The necessity of solving a common task often does not suffice to tackle serious team issues in study projects. Therefore we designed a course, where the solving of team issues is explicitely credited. We think that the robotic application, which naturally touches several fields of study is perfect as a trial for learning interdisciplinary teamwork.

All three courses shall prepare students for successfully participating in the team in case it caught their interest. These courses are one of our most important pillars for drawing new students into the team.

6 Discussion

We regard our student team as a good combination of research and teaching interests, which creates synergy effects and benefits for both students and PhD candidates. Nevertheless, there are some downsides to it, which we will elaborate further in this section.

One of the downsides, we already touched several times in this paper is the relatively high initial hurdle. We often tell interested students at open house days that everyone who can hold a screw driver at the right end can participate and contribute. This turned out to be not entirely true. The framework and the hardware we created over time needs quite some time for familiarization. Some students, which were both motivated and achieving good grades in their studies showed difficulties in learning the basics independently. Incorporating these students causes extra effort to the team members and management. Other students lost their motivation, because achievements won't come as fast as they expected. The maintenance of the right team size by acquiring new members therefore needs quite some personal supportive effort, which does not guarantee to result in any team performance improvement.

The other downside of the interrelation between the student team and the department's research is that students and research staff become more dependent on each other. PhD students often instruct one or two undergraduate students to help them with their dissertation and hand self contained parts over as projects or theses. This makes dependencies clear and simple. Through the complex dependencies between the research and the student team, publications and team performance rely more than usual on several agents of the two groups. This makes the research process more complicated but in our eyes also more realistic regarding work in the industry or in bigger research networks.

Regarding the downsides, we still draw a positive conclusion, as they are outweighed by the positive effects, we will shortly recall. Most important to us are the synergy effects between research and teaching, which bring both the fascination of research to the students and reduce the effort for lecturers to deliver good education. The student team also improves the research in the department, because the research staff works closer together over the common goal and motivation and the students in the team are better trained to help with the research than their fellow students.

Nevertheless, to achieve these synergies between the student team and the department's research, the format of the team has to be chosen carefully (see Section 2). Which competition or format is beneficial for the department depends on the department's research interests. The positive effects, we described in this paper, often only show up when this decision was taken well.

7 Conclusion

We have made very positive experiences with our student team approach and we highly recommend this kind of approach as it benefits both the research of the department and the education of students. Participation in international tournaments can also be a flagship project for the university, which draws attention to both the university and the department. Clearly, it bares some efforts, financially and regarding workload to build up and maintain such a team. The focus of the team has to be chosen carefully to match the department's research interests. Nevertheless, we were able to generate a significantly higher proportion of dissertations, to create synergy effects between research and teaching, to strengthen the team spirit between our scientific staff, to provided every team member with an extra amount of practical experience in their field of research and last but not least to have a lot of fun at tournaments and in meetings.

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