roboterfabrik: A Pilot to Link and Unify German Robotics Education to Match Industrial and Societal Demands

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Abstract. In this paper we introduce a novel robotics education concept entitled *roboterfabrik*. This approach is already implemented as a pilot project in the German educational system. Overall, we promote establishing the first generation of *robotic natives*. For this we need to provide both practical and theoretical experience in robotics to young people and give them access to state-of-the art, high performance yet affordable industrial robotic technology. Specifically, our approach systematically connects different existing school types, universities as well as companies. It comprises specialized lectures at the university, certified workshops and Robothons which are derived from the hackathon concept, and modified to the demand of roboticists.

1 Introduction and State of the Art

The significance and relevance of robotics beyond the professional community to laymen and even the general public has increased significantly over the last decade. After having enabled the third industrial revolution, robotics already arrived in our households. Lawn-mowers, cleaning robots, camera drones and robot toys have become a reality [28]. It is expected that over the next decade real service robots will enrich and facilitate our daily lives and change the way people interact with their environment. As of today collaborative robots are about to advance industrial processes in essentially all sectors [28].

This vast progress ultimately leads to the conclusion that the current generation of children is the first to grow up with real world robotics technology, making them *robotic natives* (short: *robonatives*). This is similar to the current *digital natives* generation that grew up at the advent of digital devices and today are thoroughly familiar with smartphones, IoT-devices and an omnipresent inter-connectivity between people. We coined the expression *robotic natives* in 2015 in the framework of our project *roboterfabrik*[3], which underlying concept and first results are elaborated in this paper. *roboterfabrik* aims for improving

[3] "roboterfabrik" is the literal German translation for "robot factory". More information can be found on the project website https://www.roboterfabrik.uni-hannover.de.

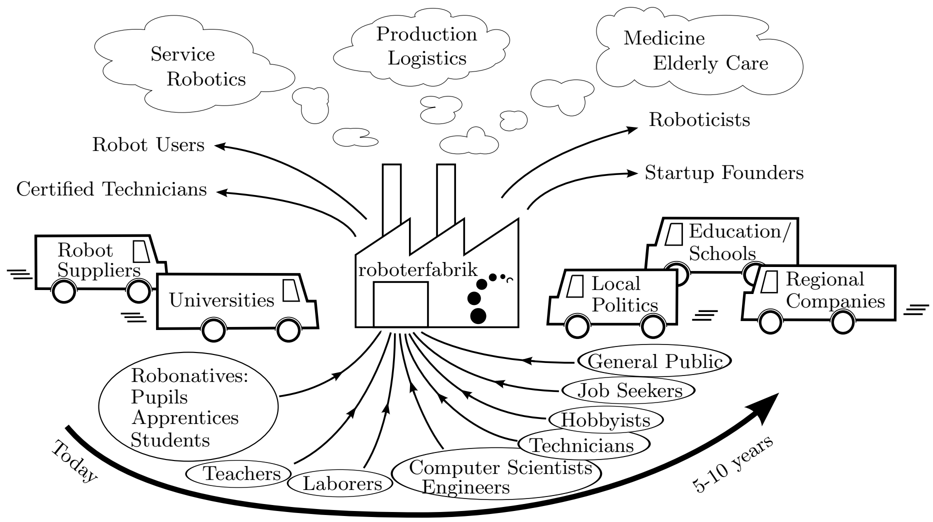

Fig. 1. Holistic concept for teaching robotics in the educational system. Different groups enter our knowledge factory *roboterfabrik*. Starting with teachers, pupils, apprentices and students in the education sector, it shall educate further societal groups in the future. Enablers such as (technical) universities, the industrial sector, local politics, the education system and robot manufacturers work closely together. This leads to qualified individuals creating benefits in different sectors by increased productivity as well as new business and technology ideas.

the robotics education of apprentices, high-school and university students starting in the region of Hanover, Germany as a pilot project [11, 12]. Our mid-term vision is to purposefully and responsibly promote this new generation of *robonatives* with suitable educational concepts. The main goal is to enable them to use and further develop state-of-the-art robotic technology, create benefits for their own lives and careers and in turn help to shape our future society.

It is both necessary and advantageous for the general public as a whole to be familiarized with robotics. Industry as well as service providers, e.g. in healthcare, will inevitably utilize robots for many dull, dangerous and time consuming tasks. Hence, technicians, computer scientists and engineers with the knowledge to program and deploy robots at various technical levels will become a common job. Moreover, since robots will become part of our everyday lives, people of various backgrounds need to be accustomed to the devices.

However, today's perception of robotics in society is well known to be rather complex. In surveys, people feel to a large extent neutral or positive when being questioned about service robots entering their homes [1, 9, 23]. At the same time, various gradations of fear are also reported [26]. More caution is found especially in the less technology-affine parts of society [5]. However, it is also known to be possible to reduce these effects by exposure to robots in the media [27] and even more by allowing experience with real robots [22]. Generally, the acceptance of robotics is not yet sufficiently studied due to biased studies [5] and unclear causalities. Furthermore, possible application areas and attitudes of general public towards robotics differ not only among countries [21] but also between group affiliations.

Generally, the robotics community has the obligation to actively inform and educate the general public [19] in order to correct expectations and avoid popular misunderstandings invoked by

1. the popular statement of robots being competitors to human workforce [8], instead of tools for humans to increase productivity, quality of life, as well as counteract the global resource distribution problem,
2. a false, often highly exaggerated expectation towards robotics induced by movies and science-fiction literature.

In this paper, we argue that these challenges should be tackled by

1. implementing a holistic approach for teaching robotics, ranging from basic education to further trainings and qualifications or workshops,
2. creating a way for the general public to encounter robots live while demonstrating possibilities and limitations.

We argue that such action would increase the motivation to use novel robotics technology and thus also societal acceptance. Consequentially, the demand for skilled workers and technical experts will increase even further, which is already intensified by the demographic change [16].

In this sense, our concept *roboterfabrik* starts at school level, where robotics may also increase the motivation to study STEM[4] subjects [4, 10]. At university level, robotics is typically started as part of the graduate level curriculum of mechanical, electrical or computer engineering faculties. Recently, the field experiences increased popularity in student numbers and some universities now offer dedicated Bachelors or Masters programs [6]. From analyzing robotics education at university level [6], however, it becomes clear that laboratory experience with highly capable articulated manipulator systems is vital. However, despite vast progress the transformation of robots from basic positioning mechanisms to work and live companions has just begun and certainly not yet arrived at the education systems. In direct consequence, our education may profit vastly from the next generation of lightweight, safe robot systems, of which the Franka Emika *Panda* is the first one [7]. Therefore, it serves as the platform of choice in our Hanover pilot project. Besides its ability to safely and sensitively interact due to its soft-robotics paradigm as well as its unmatched affordability, its App-based programming interface allows the use of cutting edge robot technology in hands-on university and even high-school projects called "Robothon". Since the learning time for handling and programming the system is very short, the project tasks may even include rather complex human-robot interaction.

Contribution: In this paper we introduce and discuss the educational concept *roboterfabrik*, which

[4] Science, technology, engineering and mathematics

1. is a pilot implementation of a holistic robotics education in the German system
2. is sought to raise the acceptance and thus general understanding of robotics in society
3. provides a methodology to improve understanding for robotics and create a certain level of expertise in the general public

The *roboterfabrik* also aims to

– establish the term *robonatives*,
– introduce Robothons (= Robotics + Marathon) as a concrete robotics education tool,
– act as a platform to share new learnings and experiences with the robotics community.

The remainder of the paper is organized as follows: The *roboterfabrik* concept and its current structural elements are introduced in Sec. 2. The evaluation of completed Robothons and further development of future ones is described in Sec. 3. The pilot implementation of our concept in the German educational system is presented as a use-case in Sec. 4. Finally, Section 5 concludes the paper.

2 Concept

In this section, we describe the vision of the *roboterfabrik* pilot project, briefly review the robot platforms used for validation, and introduce the idea of certified workshops and robothons as a key to success.

2.1 Robotics in the Education System

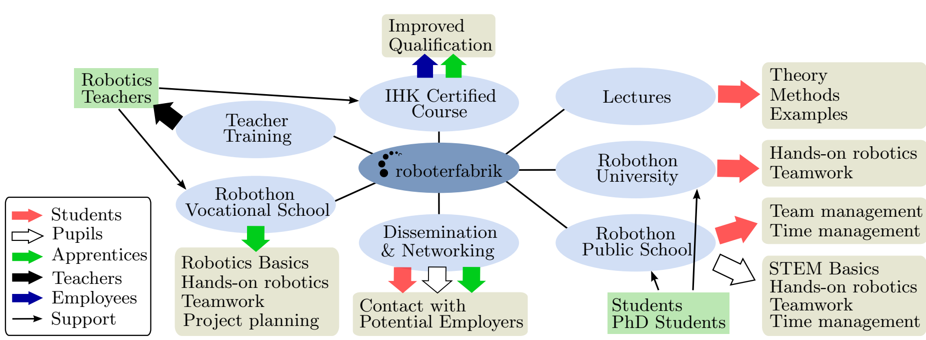

Fig. 2. The educational paths in our pilot project *roboterfabrik*. The light blue circles denote the available programs and grey boxes indicate the outcome for the different groups in the education system. The groups then connect the programs, e.g. teachers giving courses at vocational schools after they received a teacher training, or by students supervising pupils at school Robothons. (IHK = Industrie- und Handelskammer, see Sec. 4.2)

Our approach brings robotics closer to the general public, see Fig. 1. It includes all interest groups, enablers and paths of possible outcome. Robotics is sought to be included in the curricula of apprentices, high-school and university students, and stimulate participation of teachers. Laborers, technicians and job-seekers improve their qualification with certified courses, while hobbyists and the general public may experience robotic technology at first hand. Apprentices, high-school and university students will naturally benefit from advanced robotics skills in their careers and will be considered the first generation *robonatives* that followed a systematic robotics education path, see Fig. 2. Note that we intentionally include vocational school teachers since they constitute a multiplier effect in particular in the German system. The overall knowledge increase will create significant benefits to existing and future workforce. Also, it will drive innovation and increase productivity in different sectors such as service robotics, manufacturing or healthcare.

To achieve this ambitious goal, several stakeholder of the German system need to collaborate closely:

- *Universities* develop the educational programs for theoretically oriented lectures and practical courses.
- *Robot technology suppliers* provide novel robot technology and give support.
- *Politics* provides funding for schools, brings the different parties together and initiates pilot projects.
- *Regional companies* connected in chambers of commerce and industry encourage their apprentices to get access to robot technology and sponsor the educational training of their staff.
- *Vocational schools* support teachers to acquire robotics know-how and transfer knowledge directly to the apprentices.

The developed connection of these stakeholders will be further elaborated below with the help of the specific pilot project in Hanover. This focuses on potential early adopters, as these have already some prior knowledge and show motivation in the expectation of better career opportunities in the future.

Next, we introduce the concrete implementation of our workshops including a detailed explanation of the Robothons.

2.2 Robotics Focus Workshops

Robotics focus workshops are our means of reaching out to high school students, apprentices or any person interested in robotics outside a university. Our goal for the participants is to be able to program a robot within one to three hours after the first encounter. In general, the workshops are organized in a modular structure that allows choosing the right topics according to the level of experience and demands of the different target groups. As already mentioned the Franka Emika *Panda* [7] system is the standard platform in the current pilot project. Therefore, our workshops focus on human-robot collaboration and assembly skills at the moment. The specific modules are grouped into the following categories:

- *General Theory*: Instructions for which no prior knowledge is required, such as a general introduction to robotics.
- *Technical Theory*: More advanced technical theory on robotics for which basic background knowledge is required or at least recommended, e.g. the high-level use of impedance control or safety methodologies.
- *Hands-on Experience*: Practical sessions with the robot platform including programming and teaching basic tasks. An important module of this group is the final project. This is tailored around the needs of the participants and fits the duration of the specific workshop.
- *Coding Modules with Robot Application*: Advanced programming with the robotic platform at hand. For this, a solid computer science background is obligatory, e.g. for programming new apps for the *Panda* system.
- *Exams*: Final modules in which the learning success of the workshop is tested and verified, including e.g. a final theoretical test for university students.
- *Trainer Modules*: Modules specialized to training the trainers who want to offer and teach their own workshops.
- *Customer Specific Modules*: Specialized modules for specific target groups, e.g. focusing on medical robot applications for caretakers.

The workshops usually take three to five days and the attendees receive a certificate after successful completion, see Sec. 4.2. Essentially, one could draw the analogy to a robot drivers license.

2.3 Robothons

Robothons are an essential part of the overall concept and central to the robotic focus workshops. They are designed to build upon a specific entry experience level. Hence, they can be adjusted to university students with strong focus on advanced robotics education, to high school students for more basic applications or to apprentices for specific practical applications.

The developed Robothons are similar to the well known concept of hackathons in which a technical problem is solved by a group of people mostly by programming in a specified amount of time. Unlike the interpretation of other authors [18, 29], where a Robothon describes an event to build a working robot subject to a given specification, we aim at solving complete tasks and offer a well defined timely structure in small heterogeneous groups, e.g. by utilizing the *Panda* system, a 3D computer vision system and other supplementary equipment such as grippers, 3D printers, ...

Although the basic intention is always to give the students a hands-on experience in robotics, the specific topics of the Robothons may differ significantly. So far, two different types were implemented, the first focusing on human-robot collaboration and solving everyday tasks, while the other one relates to the application and development of machine learning algorithms for learning real-world assembly tasks. In the following, we refer to these specific Robothons as *collaborative Robothon* and *ML Robothon*, respectively.

Our concept stands out among others since instead of using rather toy-like systems with only marginal relation to real-world applications, we use cutting edge robot platforms that are currently introduced to real-world industry and research, i.e. the students practically experience highly relevant projects.

Typically, Robothons are integrated between a lecture and the accompanying exam. However, a Robothon may also be conceptualized as an independent module. The Robothon concept was first introduced at Technical University Munich (TUM) in 2011 as a block seminar in the lecture *Human Friendly Robotics*.

The general aim of a Robothon is to provide hands-on experience and inspire enthusiasm for novel technology that is about to hit industry. Additionally, the extensive need for teamwork promotes various soft skills. We further give students hands-on project planning experience by providing them with small project budgets to buy supplementary materials or supplies for their tasks.

The overall structure of the Robothons is outlined in the following.

Preparation Phase Prior to beginning the actual work, the students assemble in groups of up to six people with heterogeneous backgrounds. From our experience, more students per group deteriorate effectiveness since a given task can only be divided into work packages to a certain degree. The Robothon supervisors are responsible for an equal distribution of skills among the different student groups such as programming, CAD design, or computer vision. For preparation the students may take any measures they deem necessary without already having access to a robot. This may include programming of software components that might be useful such as special computer vision algorithms, or the design and 3D-printing of gripper fingers that are specific to the respective task.

In addition, we provide the students with introductory crash-courses prior to the Robothon. For example, the CAD design and the design of gripper fingers or other special endeffector tools are particularly useful. The focus lies on enabling students to spot the important success factors in their assigned task, and how to match the robot capabilities with suitable finger and tool design. Specifically, depending on the required speed and space requirements of a task it might be more efficient to design a single endeffector or finger that can handle multiple situations instead of several ones that would need to be exchanged during the process.

Another introductory course elaborates on the used robot system itself, in our case Franka Emika's *Panda* [7]. In essence, this is a shortened version of the theoretical and practical units from the previously mentioned workshop we offer to high-school students and apprentices. Since students usually have a certain theoretical robotics background already, it is sufficient to teach them how to operate the robot. Particularly, this includes learning how to effectively teach it and how to use the web interface for developing novel solutions based on existing apps. Furthermore, the students learn how to program their own apps using a hierarchical hybrid statemachine-based programming. Although we provide a standard repertoire of various apps, individual tasks usually require the students to also write their own ones.

The third type of introductory course covers the implementation of computer vision algorithms and other functionalities via services written in C++. We provide a set of standard methods such as 3D-object detection and voice recognition. They enable the students to improve the prepared solution to match the needs of their own task. Nonetheless, if they desire to integrate and connect new algorithms and methods they are free to do so.

Eventually, in a fourth course the students are introduced to common machine learning tools and methods they may utilize in their Robothon. This includes popular and widely used software packages such as TensorFlow [24], Keras [2] and SciKit Learn [25].

Robothon Phase The Robothon itself is divided into distinct phases to help the students to set goals and target advancements for the different days. This helps bringing certain structure to the student plans and encourages them to use a divide-and-conquer approach. Hence, the first day focuses on setting up the task i.e. placing all materials, involved devices and tools at the optimal location, experiencing the robot kinematics and thinking about possible solutions. In the end of the day the students present their plan, which comprises of specific work packages, milestones and assignments to group members. In the *collaborative Robothon*, we usually ask the students to solve their tasks first without the help of computer vision or other additional modalities, since this makes it easier for them to develop an initial working solution before integrating 3D vision solutions. In the *ML Robothon* a fully functional vision framework is provided as the focus of the course lies on the development of machine learning algorithms for force-sensitive assembly and insertions.

The second to fourth day contain mostly realization work, consisting of implementing the respective solution, writing skills and software if needed and improving working processes. The major milestone is to have a running application by the end of day four.

The last day is intended for optimization and implementation of additional elements that are not critical for the solution itself. Thereafter, the results are presented after a strict deadline. In addition, the developed approach together with a summary video are shown in a colloquium after the Robothon.

2.4 Reference Education Platform

Only with the availability of the intuitive, safe and affordable robot system Franka Emika *Panda* [7] it was made possible to initiate the *roboterfabrik* concept. This robot constitutes the core component and needs to be usable even by high-school students as young as fourteen years old, yet at the same time be capable of industrial grade automation. Moreover, for more advanced students who desire to graduate in robotics or some closely related field, they have to provide the necessary low-level interfaces to allow research activities and adding new features via advanced programming.

3D Perception technology such as Microsoft Kinect2 [20] and Intel RealSense SR300 [13] are also made available. The former is used as a static camera while the SR300 is mounted on the robot endeffector.

So far our setup is rather unique since there has not yet been a robot system that is both affordable and technologically relevant such as *Panda*. Most educational approaches in the robotics community make use of small mobile robots since these are usually much cheaper than complex manipulator systems, let alone soft-robotics enabled ones [6]. This of course results in major restrictions in terms of learning. Typically, the focus lies on navigation or low-level programming [14]. In contrary, we are able to offer for the first time an educational program including interaction, manipulation and learning for cutting edge soft-robots.

3 Evaluation

So far we were able to reach about 175 university students mostly from mechatronics, electrical engineering and computer science masters programs, as well as almost 100 students which were either in high school grade seven to twelve or first-year apprentices from vocational schools. The addressed topics span from human-robot collaboration in manufacturing to household robotics for the elderly. The number of Robothon participants has increased significantly over time. Impressions[5] from previous events are shown in Fig. 3.

Fig. 3. Impressions from the opening of the *roboterfabrik* with the Minister President of Lower Saxony (left), previous *collaborative Robothons* (middle) and *ML Robothons* (right).

Next, gained insights and possible evaluation metrics for future events are discussed.

3.1 Lessons Learned

The increasing number of completed Robothons provides us with the possibility to critically review the success of the events and use according feedback to continuously improve them. Lessons learned so far can be summarized as follows.

- A comparison of earlier Robothons without preparatory phase to the more recent ones clearly shows that students, who were introduced to the specific

[5] Further impressions of various events and Robothons can be found at https://www.roboterfabrik.uni-hannover.de

tools of the Robothons use more structured and well-thought-out approaches. This results in better planning at the beginning and significantly improved final results. Moreover, the comparison indicates that forming student groups should be done before the preparation phase. The safety instructions were done during the preparation phase, so the students learn early on how to safely use and interact with a robot.
– A planning phase in which the students plan their entire approach, divide their project into work packages, and distribute these among team members according to their particular skills and interests has turned out to be very important. Furthermore, due to the constrained available time frame for solving the problem at hand, an effective time management is required.
– It is necessary to provide selected software packages with high quality documentation to allow the groups a qualified decision process which packages to select for their respective tasks. Otherwise, the amount of available packages (especially the ones available in the popular ROS framework) constitutes a major hurdle. To use standardized and well-documented packages also allows the groups to work independently and decreases supervision efforts.
– It turned out to be more efficient to assign dedicated supervisors as specialists e.g. in 3D printing, computer vision or robot app development. Supervisors directly assigned to a group could hardly be trained in all hardware and software components. Thus, one or two specialists are required to provide assistance when specific questions or unforeseen problems arise.

3.2 Possible Evaluation Methods and Metrics

Among the possible *methods* for evaluating Robothons are anonymous feedback sheets as is common for all lectures at the *Gottfried Wilhelm Leibniz University Hanover*. Furthermore, structured interviews with the participants, as e.g. the ones performed in [17] to assess positive and negative influencing factors for the FH Salzburg Robothon, are used. The advantages of questionnaires are anonymity of the participants and their convenience and simplicity. Interviews on the other hand, typically provide more informations and allow to reassure given answers. However, they may be biased with respect to positive results, if the Robothon is part of graded lectures.

We used the questionnaire-type evaluation to inquire about equipment, safety measures, tasks, supervision, working atmosphere in the groups and the organization. The answers are linguistic and have to be transferred into a *metric representation* such as ”good/average/bad” or ”number of positive or negative occurrences of aspects” for statistical analysis. This, however is ongoing process and results will be published at a later stage.

4 Further Roll-Out

The roll-out of the *roboterfabrik* concept presented in Sec. 2 has started in the German pilot region Hanover. On a mid- to long-term perspective the education concept and its focus on robotics is sought to be transferred to the German dual education system (see Sec. 4.1) with a certification by the associated authorities (see Sec. 4.2). The planned transformation of the pilot project into a systematic roll-out is shortly described in Sec. 4.3.

4.1 Integration into the German Dual Education System

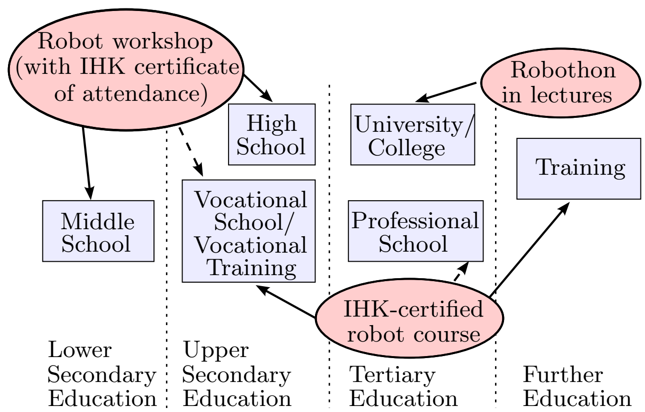

Fig. 4. Excerpt of the German education system with focus on institutions relevant for technical professions. Our approach to deliver robotics education to all levels of the system is accomplished by the robotics focus workshops (Sec. 2.2), Robothons (Sec. 2.3) and certified courses (Sec. 4.2). Solid arrow-lines point to the main targets.

The dual education system in German-speaking countries is unique. After attending public school until lower secondary level for ten years, significant numbers of students become apprentices in companies, learn practical skills necessary for future jobs and attend vocational schools at the same time to learn corresponding background theory. The apprenticeship ends after two to three years with final examinations, including theoretical exams and practical works. This system has led to high employment rates of younger people and a good body of qualified workers for German industry. As already mentioned, our goal is to integrate the *roboterfabrik* concept into the German dual education system, see Fig. 4. The courses are designed for skilled workers as industrial trainings. By providing them also to apprentices, we improve their qualification and offer them a low-threshold opportunity to become familiar with the technology. The young skilled workers then become *robonatives* by our definition and bring cutting edge robotics know-how to small and medium enterprises (SMEs), which in contrast to large companies have not yet profited at large from automation [15].

4.2 Certification

The chambers of commerce and industry ("Industrie- und Handelskammer", "IHK") are regionally organized associations of businesses, which manage major parts of the dual education system in Germany. Additionally, they offer certified training sessions that are highly valued and accepted by companies for on-the-job training of their employees [3]. A certificate course may consist of 50 to 400 (cumulated) hours of training with defined measures of learning success e.g. by tests or work samples. The first set of results from the Robothons was integrated into new certificate courses on how to use collaborative robots. An "operator certificate" course is currently developed in close cooperation with the vocational school BBS Neustadt and Franka Emika GmbH. The course is created particularly for apprentices and skilled workers, empowering the participants to set up a robot for envisaged automation tasks. This includes creating a concept for solving the task, selecting and collocating robot apps, installing a test demonstrator, learning to make the application robust and integrating the setup into a factory ecosystem with particular focus on safety and efficiency. The course will be offered in the near future at the BBS Neustadt. Teachers of the vocational school already took training courses from Franka Emika GmbH in order to be able to safely handle the robot and teach relevant skills to their students. Parts of the certificate content will be taught in the regular curriculum, while interested and motivated students have the opportunity to take further modules in order to obtain the full certificate.

Meanwhile, we are working on an "expert certificate"-course for automation engineers and programmers, which focuses on the creation of new programs and robot applications. This includes programming the robot not only via teaching, but at code level. Participants are then able to include computer vision pipelines and create state machines for advanced apps. The content of this course is roughly equivalent to the student Robothons. Students who participated in the Robothons will also receive the certificate to increase the attractiveness of the model.

To create a certificate from the Robothon concept learning targets, contents, and materials have to be reviewed, prerequisites, tests, and evaluation of the participants properly defined. Finally, course evaluation and systematic feedback are intended for quality assurance.

4.3 From Pilot Project to General Concept

The systematic integration of robotics into the university, schools as well as apprentice education (see Fig. 4) is brought together in the project *roboterfabrik*. The first pilot in Hanover developed concepts and learning materials, and collected feedback for the improvement of the process. Meanwhile, the certificate courses are built up in the regional vocational schools with the help of the chamber of commerce and industry. We also work on distributing the idea and structure of the *roboterfabrik* nation-wide, starting in the state of Lower Saxony.

5 Conclusion

Our educational concept *roboterfabrik* is regarded as a significant step towards integrating robotics into our educational system. It already led to considerable interest among universities, schools, companies and politics alike. After the very successful pilot project in Hanover, we plan to transfer *roboterfabrik* to other locations. Based on the feedback and evaluations of previous events, we continuously extend and enhance the workshops and Robothons. New workshops will be tailored in the future around specific needs of important target groups such as e.g. logistics or healthcare. At some point this could enable us to make the *roboterfabrik* concept accessible even to the general public.

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