Artificial Intelligence and Computer Science in Education: From Kindergarten to University

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***Abstract*—Artificial Intelligence (AI) already plays a major role in our daily life (e.g. intelligent household appliances like robotic vacuum cleaners or AI-based applications like *Google Maps, Google Now*, *Siri, Cortana*, . . .). Sound knowledge about AI and the principles of computer science will be of vast importance for future careers in science and engineering. Looking towards the near future, jobs will largely be related to AI. In this context literacy in AI and computer science will become as important as classic literacy (reading/writing). By using an analogy with this process we developed a novel AI education concept aiming at fostering AI literacy. The concept comprises modules for different age groups on different educational levels. Fundamental AI/computer science topics addressed in each module are, amongst others, problem solving by search, sorting, graphs and data structures. We developed, conducted and evaluated four proof-of-concepts modules focusing on kindergarten/primary school as well as middle school, high school and university. Preliminary results of the pilot implementations indicate that the proposed AI education concept aiming at fostering AI literacy works.**

***Index Terms*—Artificial Intelligence in education, AI literacy, computer science education, educational robotics, literacy, kindergarten, primary/secondary education, undergraduate education**

I. Introduction and Motivation

Artificial Intelligence (AI) plays an increasingly important role in our daily life. People use different devices, applications and services which are based on the principles of AI. Examples would be intelligent household appliances like autonomous vacuum cleaners or lawn mowers as well as services and smartphone applications like *Google (Maps, Now, . . .)*, *Cortana* or *Siri*. In contrast, hardly anybody knows about the concepts and techniques behind those services and applications. Furthermore, teaching fundamental topics of AI and computer science at school or pre-school level hardly exists at the moment [1].

Considering the current technological development, sound knowledge about AI and the principles of computer science will be of vast importance for future careers in science and engineering. Looking towards the near future, jobs will largely be related to AI as it will be the basis of the products where our future wealth will be built on (smart production, internet of things, autonomous driving, robotics . . .). In this context literacy in AI and computer science will become as important as classic literacy (reading/writing). Research in the area of classic literacy shows that starting to learn those basic skills at an early stage is essential for developing profound abilities [2], [3]. In order to develop AI literacy it is crucial as well to familiarize people with the underlying concepts of AI and computer science as early as possible.

By using an analogy with the development of classic literacy we developed a novel AI education concept for different age groups on different educational levels aiming at fostering AI literacy. Developing reading/writing literacy begins during preschool years, continues through primary, middle and high school and extends right through university. In kindergarten children are introduced to letters in a playful way, followed by a more methodological approach in primary school. Each subsequent level of education fortifies already learnt knowledge, introduces new topics and explores certain topics in depth. Based upon existing knowledge, skills are enhanced and abstraction abilities are fostered [4]. People develop and improve reading/writing skills during their whole life but as research shows the early childhood years (up to the age of eight) are crucial in classic literacy development. Acquiring profound classic literacy skills also requires continuous learning by consolidating already learnt contents and active interaction with print [5], [6].

Taking into account this knowledge and transferring it into AI literacy development, our AI education concept comprises modules for different age groups on different educational levels starting with kindergarten and primary school and continuing with middle school, high school and university (see Figure 1).

One look at the reading/writing development shows, that successful teaching builds upon already existing knowledge [7]. Considering this fact, the modules of our AI education concept build on one another, each module covering basic topics in a greater detail as well as introducing new/advanced topics. For instance, modules for kindergarten/primary school introduce fundamental AI/computer science topics (*graphs and data structures, sorting, problem solving by search*) while subsequent modules also cover advanced AI/computer science topics (*automata, intelligent agents, planning, machine learning*; also see definition of AI literacy and contents in Section III-A).

Based on this AI education concept we developed four proof-of-concepts modules focusing on kindergarten, middle school, high school and university (Sections III and IV describe the AI/classic literacy analogy for each module in detail). All four modules have already been conducted and empirically evaluated in several pilot projects.

The remainder of this paper is structured as follows: Section II provides an overview of related literature followed by Section III which defines the term AI literacy and describes our AI education concept in detail (content, structure, learning techniques, tools, stages of AI literacy development). Section IV deals with the description and evaluation of the proof-of-concept implementations. Finally, Section V summarizes our AI education concept and preliminary results and discusses conclusions, shortcomings/limitations and future work.

II. Related Literature

Looking at the current literature, teaching basic concepts and techniques of AI and computer science at school level is quite rare. To go further, teaching those topics independently from specific programming languages or learning tools (e.g. specific robotics platforms, software, ...) on different educational levels adapted for different age groups (kindergarten, primary school, middle school, high school, university) hardly exists [1]. What current approaches have in common is the relatively narrow focus on specific target- and age-groups (graduates/undergraduates, certain school levels).

Many existing approaches focus on teaching AI concepts to undergraduate or graduate students at university/college (e.g. Torrey [8], McGovern et al. [9], Kumar and Meeden [10], Torrey et al. [11], Li et al. [12], Barik et al. [13], Albu [14]) or in teacher training (e.g. Dilger [15]). Approaches which teach selected topics of AI at school level like Heinze et al. [16] or Fok and Ong [17] only deal with certain aspects of AI (e.g. history, Turing Test [18], chat bots, neural networks) or only use specific tools or platforms to illustrate AI concepts (e.g. Featherston et al. [19]). Other approaches focus on certain programming paradigms relevant to AI (e.g. declarative programming in high schools as described by Reyes et al. [20]) or are only partially focused on certain AI topics (e.g. Layer et al. [21]). Various approaches exist which aim at fostering STEM or STEM-C education (science, technology, engineering, mathematics, computer science; e.g. Bojic and Arratia [22] describe a project which introduces school students (K-8 up to K-12) to STEM-C fields; Tsukamoto et al. [23] discuss an approach of teaching primary school students programming using a text-based language). Many approaches exist which use AI as a learning tool (e.g. Pareto [24]) in terms of Artificial Intelligence in Education (AIED; e.g. intelligent tutoring systems, interactive learning environments, ... [25]).

Sklar and Parsons [26] discuss how robotics and robotics competitions (in particular *RoboCupJunior*) could be a vehicle to introduce school students to AI, robotics and computer science. Furthermore, they outline the use of robotics in undergraduate education to teach AI and computer science. In this context the authors define the term *technical literacy* as *"comfort with and understanding of technology"*. Thus, technical literacy means understanding topics like state machines, dynamic systems, search heuristics, planning, logic, knowledge representation and uncertainty. In line with this definition we introduce the more specific term *AI literacy* and present a comprehensive AI education concept that addresses kindergarten children, primary and middle school students, high school students as well as undergraduate university students (see Section III).

III. Methodology

A. AI Literacy

In the near future profound knowledge about AI and computer science will be the basis for careers in science and engineering since more and more AI based products and services will emerge. In this context literacy in AI constantly gains importance and will become almost as important as classic literacy (reading/writing literacy). Classic literacy enables people to read and understand new text, instead of learning a text just by heart [26]. The same applies to AI literacy: It allows people to understand the techniques and concepts behind AI products and services instead of just learning how to use certain technologies or current applications.

Our definition of AI literacy comprises following major topics of AI/computer science [1] (based on the common textbook by Russell and Norvig [27]; also see Figure 2)

- **Automata** form the basis for describing systems and behaviors and illustrate the decision making process in an illustrative fashion.
- **Intelligent agents** such as simple reflex, model-based reflex, goal-based or utility-based agents are suitable vehicles to demonstrate the modelling process of making and executing decisions. The concept of intelligent agents combines many different AI topics which can be imparted to students and children in a suitable and understandable form (e.g. using robots)
- **Graphs and data structures** (stack, queue, trees, ...) as well as **basics of computer science** (control statements, paradigms, data storage) and the **definition of a problem** (in the context of AI) form the basis for any task in AI and computer science.
- **Sorting** represents another fundamental concept in AI/computer science (algorithms such as bubble-, merge-, insertion-, selection-, quick-sort, ...).
- **Problem solving by search** is an essential concept in AI and one of the main emphases of AI literacy with numerous areas of application, such as Constraint Satisfaction Problems (CSP), Satisfiability Problems (SAT solving) or planning. Basic algorithms in this context are breadth-first search, depth-first search and A* search.
- **Classic planning** (modeling problems, making decisions, establishing and evaluating plans) as well as **logic** (under-

standing logical operators, performing logical reasoning) are important topics in AI [26]. Concepts to be considered are, amongst others, state-space planning, forward and backward chaining as well as propositional and predicate logic.

- **Machine learning** is an interesting and very motivating topic for students which gains more and more importance. Contents to be considered are, amongst others, different approaches to learning agents (e.g. logic-based learning, knowledge based systems, reinforcement learning) as well as decision trees and neural networks.

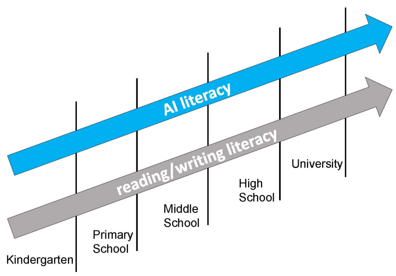

Fig. 1. Development of AI literacy in analogy with classic literacy (reading/writing) on different educational levels

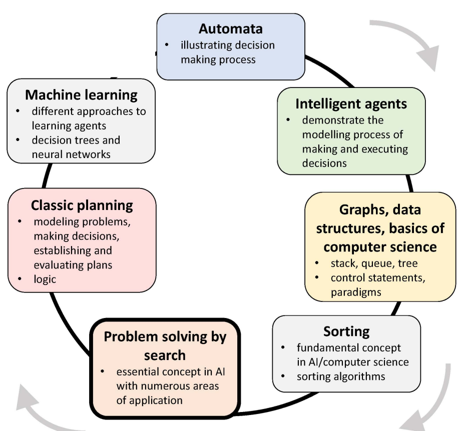

Fig. 2. Topics of AI literacy

Neuman et al. [5], [6] propose a multi-stage view on reading/writing (r/w) development in order to adapt learning methods and goals in an age-appropriate way (*1: awareness and exploration; 2: experimental r/w; 3: transitional r/w; 4: independent and productive r/w; 5: advanced r/w*). In analogy with this model we define the following stages regarding AI literacy development:

1) building awareness and playful exploring AI topics (kindergarten, primary school);
2) experimenting and familiarizing with the theory behind certain AI topics and working independently on solving a problem (middle school);
3) fostering core AI topics and getting familiar with advanced AI topics; independently acquire and apply knowledge (high school);
4) becoming 'fluent' in AI; applying problem solving methods on a higher abstraction level; fostering fundamental understanding of AI topics (university);

B. AI Education Concept

By using an analogy with the development of reading/writing literacy (as described in Section I) we developed an AI education concept aiming at fostering AI literacy. The concept comprises modules for different age groups on different educational levels (kindergarten, primary school, middle school, high school, university; see Figure 1). Fundamental (core) AI topics addressed in each module are, amongst others, *graphs and data structures*, *sorting* as well as *problem solving by search*. The modules build on one another, each module covering the core topics in a greater detail as well as introducing new/advanced topics.

Education research has shown the positive impact of hands-on experiences on learning [26], [28], hence the modules are largely based on the principles of constructionism [29], [30] comprising a wide range of hands-on activities. Each module applies appropriate learning methods and techniques (discovery learning, inquiry learning, collaborative learning, problem-based learning, project-based learning, storytelling, peer teaching; [31], [32], [33], [34]), respectively combinations of these methods as suggested in [35]. Furthermore, in each module a number of different learning tools and platforms are used (educational robotics, computer science unplugged, educational games, paper-and-pencil; [36], [37], [38]).

In analogy with research in the area of classic literacy the activities in each module are embedded in meaningful, enjoyable experiences. The goal is to familiarize children and school students with AI topics while they experience motivational, interesting and inspirational activities [39], [40], [41]. The following sections provide an overview of contents, structure and goals of each module.

C. Kindergarten and Primary School

Research in the area of classic literacy shows that it is essential to start to learn basic reading/writing skills at an early stage [2], [3]. Furthermore, studies show that it is important that children gather experience with books in order to make connections between printed and spoken word [42]. In order to develop AI literacy it is crucial as well to a) familiarize children with the basic concepts of AI/computer science as early as possible and b) to let the children discover the connection between AI applications and the underlying concepts.

The idea behind this module is to introduce kindergarten and primary school children (aged between four and eight years) to the core AI/computer science topics in a **playful way** by breaking down complex contents in an age-appropriate fashion [31] (according to stage 1 defined in Section III-A).

Respecting pedagogical and didactic aspects we developed different hands-on units where children can actively participate and explore AI/computer science topics [33]. We applied methods of discovery- and inquiry-learning [35], [43], the technique of storytelling [34] as well as the principles of educational robotics [32], [36] and computer science unplugged [38]. In this context we used different learning tools (robotics platforms like *Bee-Bots* [44], *LEGO Mindstorms NXT* [45] and *Cubelets* [46] robotics kits, but also non-robotics material like standard LEGO bricks).

Following an overview of AI/computer science topics covered in several hands-on units (including a sample activity for each topic [47]).

- **graphs and data structures** (e.g. programming a Bee-Bot to traverse a graph in order to find a way out of a maze)
- **sorting algorithms** (e.g. sorting LEGO bricks according to the bubble sort algorithm)
- **problem solving by search** (e.g. children have to traverse a graph from the root (nodes and edges are taped on the floor) to a certain node (where a 'treasure-box' is located); to demonstrate blind search, children wear a special helmet were they can only see the next edge of the graph; also see Figure 3)

The hands-on units can be combined modularly, depending on how this module is being implemented in kindergarten/primary schools (see Section IV for the description of a pilot implementation).

D. Middle School

Looking at reading/writing literacy in later years of education, the focus of teaching shifts more towards supporting children to develop independent reasoning and comprehension skills. Children should be encouraged to analyze different topics, formulate questions and organize written answers by giving them challenging tasks [5], [6].

Applying this knowledge to our AI literacy approach, in this module school students (aged between eleven and thirteen years) take a first look at the theory behind certain AI topics and apply this knowledge afterwards in a practical group project encouraging them to analyze and work independently on solving a specific problem (stage 2 of AI literacy development, see Section III-A). Hence, this module comprises theoretical and hands-on elements based on the principles of constructionism and instructionism [29], [39] applying project-based, collaborative learning and problem-solving methods [35]. Learning tools used in this module are the educational robotics platform LEGO Mindstorms NXT as well as paper-and-pencil and computer science unplugged exercises.

The module fosters core AI topics, in particular graphs and data structures as well as problem solving by search. Furthermore, it introduces the concept of intelligent agents. After completing this module school students should have a basic idea of fundamental data structures and search algorithms and **understand the connection between those AI techniques and common AI applications** (e.g. Google Maps). Basically the module is structured as follows:

- raising a guiding research question (e.g. *"What does AI have to do with graphs, algorithms and Google Maps?*)
- motivation, raising awareness for the topics (e.g. navigating to a given location using Google Maps as well as a conventional map)
- introducing school students to **graphs/trees and data structures** (*stack, queue*; applying educational games, paper-and-pencil/unplugged exercises and programming exercises)
- introducing students to **search algorithms**, in particular *depth-first (DFS) and breadth-first search (BFS)* (paper-and-pencil exercise, group discussion regarding differences and advantages of those basic search algorithms, programming)
- familiarizing students with **intelligent agents** (constructing a robot equipped with sensors)
- programming a robot to explore a small maze (finding the exit) and evaluate, compare and document different search strategies/algorithms (random, wall-follow, DFS, BFS)

This module is designed to be implemented in form of a research week/camp or in form of weekly courses (Section IV describes a pilot implementation). The modular design allows implementations with different levels of complexity/difficulty (e.g. for school students with or without prior knowledge in AI/robotics/computer science).

E. High School

In this phase reading/writing abilities are fortified based on already existing knowledge, certain topics are explored in depth and new topics are introduced [4]. According to this development and in line with our AI literacy concept (stage 3 as described in Section III-A) the goal of this module is to foster core AI topics by exploring them in a detailed way, introducing advanced AI topics as well as to foster the ability to acquire and apply AI topics independently.

Based on the principles of constructionism and constructivism [30], [36] school students (aged between 15 and 18 years) actively participate in the learning process. Activities include paper-and-pencil/programming exercises, robot constructions, discussions, group works and home-assignments by applying inquiry- and collaborative learning and problem-solving methods [35].

After completing this module school students should be familiar with all topics of AI literacy as defined in Section III-A. Following an overview of the topics, structure and sample activities in this module [1], [27], [48].

- **automata** (e.g. defining a finite state machine representing the simplified control of a vending machine)
- **intelligent agents** (e.g. building Braitenberg vehicles [49] using LEGO Mindstorms NXT robotics kits)
- **graphs and data structures** (including sorting) (e.g. programming a robot to explore a small maze and building the corresponding graph)
- **problem solving by search** (introducing school students to the breadth-first-, depth-first- and A*-search algorithm by discussing the theory behind, analyzing

each algorithm, doing paper-and-pencil exercises and by implementing the A* algorithm in C#; also see Figure 5)

- **classic planning and logic** (e.g. solving a planning problem with given initial-/goal-state and actions with pre-/post-condition; in order to simulate the 'computer's view' on this problem and to block out students' common sense the whole problem domain is masked (e.g. substituting the goal state *Have(Bananas)* as *Eahv(Nnaaabs)*).
- **machine learning** (e.g. discussing and analyzing different approaches to learning agents)

Due to its extensive content this module is designed to be implemented on a weekly basis (e.g. as an optional subject with 1-2 hours per week; see Section IV for a pilot implementation).

F. University

In order to follow our analogy to reading/writing literacy, at university level we aim at a more **fundamental understanding of the topics** and the enabling of further developments in the field. The former aims at the educational aspect in order to develop a professional career. In the context of writing and reading people will use the written language as a core component of their profession. For instance, at university level people are educated to become teachers, journalists or translators. In order to do so a sound understanding of the concepts and models behind but also methods as well as the properties of all of them are needed.

In the context of AI that means the capability to **describe problems formal**, precise and on a much **higher abstraction level**. Moreover, also the understanding of properties of problems and the relation and the mapping of different problems is important because it allows to reuse powerful solving methods. Finally, the knowledge about properties of problems such as complexity are relevant in the context of AI. The latter aims at research where fundamental questions are raised that research tries to answer in order to better understand the own field (i.e. better models) or do extend the portfolio of applicable methods. This endeavor can be related to reading/writing with a strong connection to language as well as AI (as part of computer science).

The university module consists of course-based education in the area of theory of computation and AI based on classical textbooks [27], [50]. In order to support a better learning we are following the idea of constructionism and use demonstrative hand-on exercises.

IV. Pilot Implementations and Preliminary Results

Based on our AI education concept we developed, conducted and evaluated proof-of-concept implementations for each of the modules described in the previous sections.

A. Evaluation Methodology

The evaluation was done using a number of reliable qualitative and quantitative empirical research methods [51]. In order to collect qualitative data we applied techniques of participant observation using both passive and active participation methods [52] (field notes, discussions, informal interviews). Furthermore, we applied the technique of semi-structured interviews using a set of predefined questions as guideline [53]. A content analysis [54] was performed after transcribing all recorded interviews and summarizing inherent quantitative data. In addition we also took pictures and made videos during each pilot implementation. Applying a grounded theory approach we collected and afterwards analyzed the collected qualitative data using open and selective coding [31], [55].

In terms of quantitative evaluation we applied paper-and-pencil questionnaires (3- and 5-point Likert scale, open ended and multiple choice questions (MCQ)), self- and foreign-evaluation of acquired skills [56] as well as feedback questionnaires. The questions were selected in order to provide feedback on content, structure, teaching style and presentation of topics.

For each module and each age group appropriate evaluation methods were applied. Considering ethical and legal aspects all collected data were treated confidentially and personal information was made anonymous [1], [57].

The subsequent sections describe pilot implementations as well as evaluation methodology and (preliminary) results for each module. In addition, the overview table in Figure 7 provides a summary of topics and results.

B. Module 1 - Kindergarten

The first module was implemented in a kindergarten in terms of a scientific project day [47], [57]. Ten different units dealing with AI/computer science topics were developed and carried out on separate hands-on areas. According to the concept of peer teaching [58] students of the school for kindergarten pedagogy hosted and explained the units to the kindergarten children accompanying them through their way of discovering and experiencing. In preparation for their tasks, school students attended several workshops at university where they were introduced to the principles and concepts of AI, computer science and robotics. Furthermore, they were also actively involved in the development of age-appropriate activities for each unit.

In sum 24 kindergarten children (average age 5 years; 54% female, 46% male) and 10 school students for kindergarten pedagogy (average age 16 years; all female) participated.

Evaluation: Preliminary results of a first analysis of collected data (mainly qualitative) indicate that our goal of introducing kindergarten children to fundamental AI/computer science topics in a playful way worked well. Video data, pictures and observations (field notes) during the project day indicate that children a) joyfully explored the different units and b) understood the (simplified) AI concepts and carried out most of the activities in each unit correctly. Semi-structured qualitative interviews with pedagogy school students and kindergarten pedagogues support these observations. For instance, after a short explanation/demonstration kindergarten children were able to sort LEGO bricks using the bubble sort algorithm.

In addition, we asked the children several days after the project day to draw pictures of their most memorable unit. This is a common approach to assess the learning success of pre-school children [59]. It turned out that children draw pictures of robots traversing graphs or finding ways out of labyrinths (see Figure 3). These findings underpin the results of the qualitative data analysis.

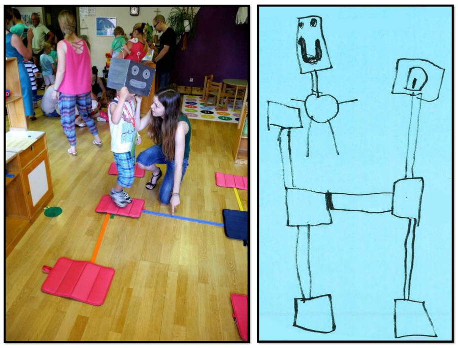

Fig. 3. left: children traverse a graph (with helmet) to introduce them to blind search (the goal is to find the 'treasure box' node); right: drawing of a child describing this activity several days afterwards (you can see the child with helmet including the traversed graph and the goal node with the treasure box)

C. Module 2 - Middle School

This module was implemented in form of a summer research week (three days, six hours per day) for middle school students at the university's robotics lab. In sum 24 school students (8% female, 92% male) with an average age of 12 years participated. Participants were familiar with the graphical LEGO programming language but had no prior knowledge in AI. Basically we followed the structure as described in Section III-D. Since most of the students were not familiar with text-based programming we also gave an introduction to NXC (C based programming language for LEGO Mindstorms robots). Furthermore, we provided students a framework where all basic robot functionalities (sensor reading, motor control, ...) were already implemented. Therefore students could focus on implementing and testing different search strategies (*random, wall-follow, depth-first search*; see Figure 4). Due to lack of time we decided to introduce students to the topics *breadth-first search*, *stack* and *queue* by unplugged exercises rather than implementing those concepts in NXC. To foster team-work, students worked in pairs. Respecting students' attention span those technical sessions were embedded in various other activities (games, sports, short soldering exercises, ...).

Evaluation: To evaluate this module on a broad basis we collected data from several sources applying various evaluation techniques:

- assessing student's prior knowledge (group discussion)
- foreign-evaluation of skills (13 item MCQ post-questionnaire; e.g. *"What are the characteristics of depth-first search?"*)
- field notes (participant observation)
- pictures and videos taken during the week
- students' feedback and self-evaluation post-questionnaire (3-point Likert scale; e.g. *"How would you rate your knowledge about search algorithms?"*)
- students' solutions of the tasks (implemented programs)
- students' documentations (results of their experiments)
- students' final presentation of their work at the end of the week

Summarizing the (preliminary) results of the data analysis the objectives of this module have partly been met. On the one hand students got a basic understanding of graphs, trees and data structures (stack, queue) as well as of different search strategies and their characteristics (pros, cons). This is documented by the post-questionnaire, observations, students' documentations, program code and final presentations. According to the feedback questionnaire and our observations students were enthusiastic and liked the tasks, which they described as challenging but not too difficult. On the other hand it turned out that students had problems to understand the connection between the basic AI concepts and their application (e.g. navigation systems, ...). The reason might be that, due to lack of programming experience and lack of time, students were too focused on the programming task so they were not able to make connections and to see the overall picture. Therefore we either have to reduce the programming effort as well as the amount of topics addressed or to provide more time (e.g. by increasing number of days).

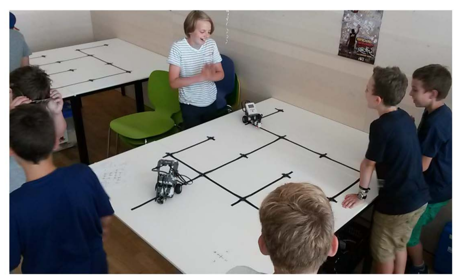

Fig. 4. Implementing and testing different search algorithms for a given graph using LEGO Mindstorms robots (middle school module)

D. Module 3 - High School

We conducted this pilot implementation as an elective course at a representative high school which integrates robotics in the regular curriculum. The course was held weekly by university researchers and comprised seven teaching units. In sum nine high school students with an average age of 16.5 years (1 female, 8 male) voluntarily participated. They all had prior knowledge in robotics (also in terms of participating in junior robotics competitions) but none in AI. In general we followed the structure defined in Section III-E. Some contents were slightly adapted and put in context with students' background and knowledge in robotics/junior robotics competitions (e.g. using search algorithms to improve the performance of students' competition robots) [1], [48]. Figure 5 shows, as an example, high school students researching the A* search algorithm.

Evaluation: We evaluated this pilot implementation applying following evaluation techniques:

- self-evaluation of skills post-questionnaire (3-point Likert scale; e.g. *"I am able to explain the principles of the A* search algorithm"*)
- feedback questionnaire on teaching style and structure of the units (open ended and 5-point Likert scale questions; e.g. *"Contents were prepared and explained in a clear and understandable manner"*)
- semi-structured qualitative interviews with each of the high school students (covering motivation, expectations, lessons learned, memorable topics/situations, experiences, ...)
- collecting qualitative data by taking pictures and field notes during each teaching unit

Summarizing the evaluation results, the pilot implementation succeeded in familiarizing high school students with a broad range of fundamental AI topics. Results indicate that students got a well founded understanding of almost all AI literacy topics (as defined in Section III-A) except for some sub-topics (architectures for agents, propositional logic). Here additional input/help would be necessary. According to students' self-evaluation they had a very positive feeling about their gained knowledge.

Although students had partly different expectations prior to the course they finally were motivated and enjoyed learning and applying fundamental AI techniques. In addition, they provided overall positive ratings on structure and teaching style of the course. Finally, students will benefit from the acquired content in future (e.g. participating in robotics competitions, writing final high school theses, starting engineer or science studies at university) [1], [48].

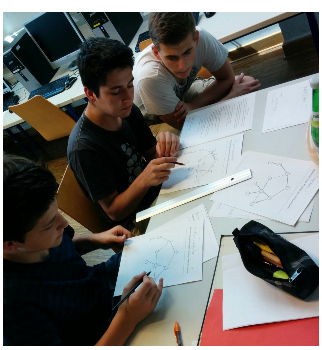

Fig. 5. High school students researching the A* search algorithm (understanding the algorithm by analyzing source code based on the given graph) [48]

E. Module 4 - University

At university level we have conducted a course on basic AI techniques at the bachelor level for several years. Besides topics such as logic or CSP (constraint satisfaction problem) we focused on the abstract description of dynamic systems like robots in order to allow to plan for this systems or to reason about. For this we use the situation calculus [60]. The advantage of this representation is that it has a strong theoretical foundation based on first order logic and leads to elegant descriptions. Moreover, there is the language *Golog* which is based on the calculus and can directly be used to program agents. The problem of the language and its interpreter is that the theory is quite complex and the tools are very clumsy and counterintuitive. Therefore, in the early stage many students failed in finishing their practical assignment. The two main reasons for that was the Golog interpreter that has no clear syntax and the results of a program run was just printed to a text console.

In order to overcome these problems we developed the new program language *YAGI* (Yet Another Golog Interpreter) that is still based on the concept of the situation calculus but has a clearly defined syntax and semantics and is closer to common programming languages such as C++ [61], [62]. Moreover, we developed the general simulation environment ASRAEL (Abstract Simulator for Research and Education in AI) which is based on the game engine *Unity* [63]. It allows to control an agent in different environments via a simple socket-based interface. We developed different environments such as the classical wumpus world [64] or a service robot in a kitchen (see Figure 6). The simulation can be easily hooked up with different AI systems and allows an appealing and motivating visualization of students' solutions.

Evaluation: By using motivational hands-on exercises (controlling an agent in an environment and a teaching vehicle that is much handier but still focuses on the basic concepts of the situation calculus) almost all students now successfully complete the course (usually we have around hundred students in this course). After completing the course students have a deeper understanding of AI topics on a higher abstraction level. We are currently developing a more detailed evaluation questionnaire (MCQ, self-evaluation, feedback) which will be applied during the next winter semester.

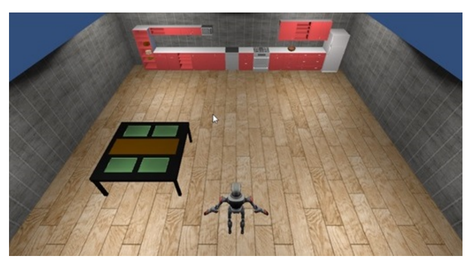

Fig. 6. ASRAEL simulation of a service robot in a kitchen (university module).

V. Conclusion and Future Work

Artificial Intelligence (AI) already plays a major role in our daily life. Profound knowledge about AI and the principles of computer science will be of vast importance for future careers in science and engineering since jobs will largely be related to AI (smart production, internet of things, autonomous driving,

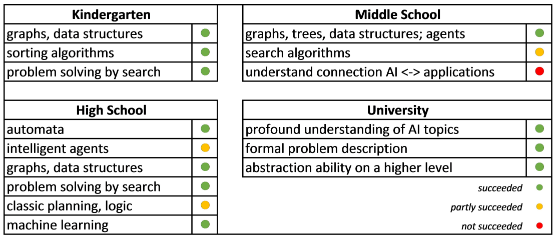

Fig. 7. Overview of topics covered in each module and evaluation results (regarding success in reaching the goals of each module)

robotics, …). Nevertheless, teaching fundamental topics of AI and computer science at school or pre-school level hardly exists at the moment [1].

In this paper we presented our approach of fostering AI literacy by using an analogy with the development of reading/writing literacy. In order to achieve this goal we developed a novel AI education concept for different age groups on different educational levels (kindergarten/primary school, middle school, high school, university). We defined relevant AI literacy topics and described content and structure of the AI education concept as well as applied learning techniques and tools. Furthermore, we conducted and empirically evaluated four proof-of-concept projects focusing on kindergarten, middle school, high school and university.

Preliminary results of pilot implementations for each module indicate that the proposed AI education concept aiming at fostering AI literacy works. The proof-of-concept implementation in a representative kindergarten (in form of a project day) showed that children (average age 5 years) explored fundamental AI topics in a playful way and understood the (simplified) AI concepts. The module for middle school students (average age 12 years) was implemented as a research week at university. Results of this pilot project indicate that, on the one hand, students got a basic understanding (theory plus practical implementation) of basic AI/computer science topics but, on the other hand, had problems to understand the connection between the basic AI concepts and their application in real life (e.g. in navigation systems). The module for secondary school students (average age 16.5 years) was implemented as a weekly elective course in a representative high school. Results show that after completing the course students were familiar with a broad range of fundamental AI topics and got a well founded understanding of all AI literacy topics (as defined in Section III-A). At university level a course on basic AI techniques (for bachelor students) was conducted for several years. By applying new learning tools and motivational hands-on exercises almost all students now successfully complete the course.

We are aware that the AI education concept and the pilot implementations presented in this paper have some limitations and shortcomings. By now we did not implement a proof-of-concept project in a primary school. Therefore, we have no data whether the activities developed for this age group/educational level would work or not. In this context we are currently working on a separate module focusing on primary school children aged between eight and ten years of age. The content and topics for middle school students turned out to be too extensive for the short time available. Therefore, our plan is to adapt and implement this module as part of an elective course in a representative middle school. Due to the relatively small sample of participants (except for the university module) evaluation results only provide preliminary insights and first hints. In order provide more sound underlying data which documents the success of our concept, we plan to conduct and evaluate further implementations in different kindergartens, schools and universities. To gather valid long-term data we have to follow a group of students who complete the entire program, from kindergarten to university. Finally, we have to mention that our approach of using an analogy with the development of reading/writing literacy is only one possibility. Analogies with other literacies (mathematics, science, …) might be conceivable as well.

In depth analysis of all collected data during the pilot implementations is still ongoing. Results and lessons learned from the first proof-of-concept projects form the basis to adapt, improve and extend the AI education concept, pursuing our long-term goal of fostering AI literacy.

References

[1] H. Burgsteiner, M. Kandlhofer, and G. Steinbauer, "iRobot: Teaching the Basics of Artificial Intelligence in High Schools," in *6th Symposium on Educational Advances in Artificial Intelligence*, Phoenix, USA, 2016.
[2] E. Myberg, "The effect of formal teacher education on reading achievement of 3rd-grade students in public and independent schools in Sweden," *Educational Studies*, vol. 33, no. 2, pp. 145–162, 2007.
[3] A. A. Genlott and A. Gronlund, "Improving literacy skills through learning reading by writing: The iWTR method presented and tested," *Computers and Education*, vol. 67, pp. 98 – 104, 2013.
[4] C. Bereiter, "Development in writing," L. W. Gregg and E. R. Steinberg, Eds., Hillsdale, USA, 1980.
[5] NAEYC, "Learning to Read and Write: Developmentally Appropriate Practices for Young Children. A joint position statement of the International Reading Association and the National Association for the Education of Young Children," *Young Children*, vol. 53, no. 4, pp. 30–46, 2013.
[6] S. B. Neuman, C. Copple, and S. Bredekamp, *Learning to Read and Write: Developmentally Appropriate Practices for Young Children*. Mcgraw-Hill, 2000.
[7] S. Neuman and K.Roskos, Eds., *How can we enable all children to achieve? In Children achieving: Best practices in early literacy*. International Reading Association, 1998.
[8] L. Torrey, "Teaching Problem-Solving in Algorithms and AI," in *3rd Symposium on Educational Advances in Artificial Intelligence*, 2012.
[9] A. McGovern, Z. Tidwell, and D. Rushing, "Teaching Introductory Artificial Intelligence through Java-Based Games," in *2nd Symposium on Educational Advances in Artificial Intelligence*, 2011.
[10] D. Kumar and L. Meeden, "A Robot Laboratory for Teaching Artificial Intelligence," in *29th Technical Symposium on Computer Science Education*, Atlanta, USA, 1998.
[11] L. Torrey, K. Johnson, S. Sondergard, P. Ponce, and L. Desmond, "The Turing Test in the Classroom," in *6th Symposium on Educational Advances in Artificial Intelligence*, Phoenix, USA, 2016.
[12] Z. Li, L. O'Brien, S. Flint, and R. Sankaranarayana, "Object-Oriented Sokoban Solver: A Serious Game Project for OOAD and AI Education," in *IEEE Frontiers in Education Conference (FIE)*, 2014, pp. 788–791.
[13] T. Barik, M. Everetty, R. E. Cardona-Rivera, D. L. Roberts, and E. F. Gehringer, "A Community College Blended Learning Classroom Experience through Artificial Intelligence in Games," in *IEEE Frontiers in Education Conference (FIE)*, 2013, pp. 1525–1531.

[14] A. B. Albu, "Learning Artificial Intelligence Clip by Clip," in *IEEE Frontiers in Education Conference (FIE)*, 2012, pp. 789–794.

[15] W. Dilger, *Künstliche Intelligenz in der Schule*. Technische Universität Chemnitz, 2005.

[16] C. Heinze, J. Haase, and H. Higgins, "An Action Research Report from a MultiYear Approach to Teaching Artificial Intelligence at the K6 Level," in *1st Symposium on Educational Advances in Artificial Intelligence*, 2010.

[17] S. Fok and E. Ong, "A high school project on artificial intelligence in robotics," *Artificial Intelligence in Engineering*, vol. 10, no. 1, pp. 61–70, 1996.

[18] S. M. Shieber, Ed., *The Turing Test: Verbal Behavior as the Hallmark of Intelligence*. MIT Press, 2004.

[19] E. Featherston, M. Sridharan, S. Urban, and J. Urban, "DOROTHY: Enhancing Bidirectional Communication between a 3D Programming Interface and Mobile Robots," in *5th Symposium on Educational Advances in Artificial Intelligence*, 2014.

[20] M. Reyes, C. Perez, R. Upchurch, T. Yuen, and Y. Zhang, "Using Declarative Programming in an Introductory Computer Science Course for High School Students," in *6th Symposium on Educational Advances in Artificial Intelligence*, Phoenix, USA, 2016.

[21] R. Layer, M. Sherriff, and L. Tychonievich, "Inform, Experience, Implement - Teaching an Intensive High School Summer Course," in *IEEE Frontiers in Education Conference (FIE)*, 2012, pp. 122–127.

[22] I. Bojic and J. Arratia, "Teaching K-12 students STEM-C related topics through playing and conducting research," in *IEEE Frontiers in Education Conference (FIE)*, 2015, pp. 548–555.

[23] H. Tsukamoto, Y. Takemura, H. Nagumo, I. Ikeda, A. Monden, and K. Matsumoto, "Programming education for primary school children using a textual programming language," in *IEEE Frontiers in Education Conference (FIE)*, 2015, pp. 1008–1014.

[24] L. Pareto, "A teachable agent game engaging primary school children to learn arithmetic concepts and reasoning," *International Journal of Artificial Intelligence in Education*, vol. 24, no. 3, pp. 251–283, 2014.

[25] I. Roll and R. Wylie, "Evolution and Revolution in Artificial Intelligence in Education," *International Journal of Artificial Intelligence in Education*, vol. 26, no. 2, pp. 582–599, 2016.

[26] E. Sklar and S. Parsons, "RoboCupJunior: A Vehicle for Enhancing Technical Literacy," in *AAAI Mobile Robot Competition 2002, Papers from the AAAI Workshop*, Edmonton, Canada, 2002.

[27] S. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach*. Pearson, 2009.

[28] H. Gruber and J. Voneche, Eds., *The Essential Piaget*. Basic Books, 1977.

[29] S. Papert, *Mindstorms: Children, Computers, and Powerful Ideas*, 2nd ed. Basic Books, 1993.

[30] S. Papert and I. Harel, "Situating constructionism," *Constructionism*, vol. 36, pp. 1–11, 1991.

[31] M. Virnes and E. Sutinen, "Topobo in kindergarten: educational robotics promoting dedicated learning," in *17th International Conference on Computers in Education*, Hong Kong, 2009.

[32] E. Romero, A. Lopez, and O. Hernandez, "A Pilot Study of Robotics in Elementary Education," in *10th Latin American and Caribbean Conference for Engineering and Technology*, Panama City, Panama, July 2012.

[33] S. Frangou, K. Papanikolaou, L. Aravecchia, L. Montel, S. Ionita, J. Arlegui, A. Pina, E. Menegatti, M. Moro, N. Fava, S. Monfalcon, and I. Pagello, "Representative examples of implementing educational robotics in school based on the constructivist approach," in *Workshop at International Conference on Simulation, Modeling and Programming for Autonomous Robots*, Venice, Italy, 2008, pp. 54–65.

[34] S. Masemann and B. Messer, *Improvisation und Storytelling in Training und Unterricht*. Beltz, 2009.

[35] H. Altin and M. Pedaste, "Learning approaches to applying robotics in science education," *Journal of Baltic Science Education*, vol. 12, no. 3, pp. 365–377, 2013.

[36] D. Alimisis, Ed., *Teacher Education on Robotics-Enhanced Constructivist Pedagogical Methods*. School of Pedagogical and Technological Education, 2009.

[37] B. Barker, G. Nugent, N. Grandgenett, and V. Adamchuk, Eds., *Robots in K-12 Education. A New Technology for Learning*. Premier Reference Source, 2012.

[38] T. Bell, I. Witten, and M. Fellows, *Computer Science Unplugged: Off-line activities and games for all ages*. Computer Science Unplugged, 1998.

[39] G. M. Johnson, "Instructionism and Constructivism: Reconciling Two Very Good Ideas," in *ERIC Institute of Education Sciences*, Edmonton, 2005.

[40] D. Stickland, *Teaching phonics today: A primer for educators*. International Reading Association, 1998.

[41] C. Snow, M. Burns, and P. Griffin, Eds., *Preventing reading difficulties in young children*. National Academy Press, 1998.

[42] K. Denton and J. West, *Children's reading and mathematics achievement in kindergarten and first grade*. National Center for Education Statistics, 2002.

[43] R. Mayer, "Should there be a three-strikes rule against pure discovery learning?" *American psychologist*, vol. 59, no. 1, 2004.

[44] P. Janka, "Using a Programmable Toy at Preschool Age: Why and How?" in *Teaching with robotics: didactic approaches and experiences. Workshop of International Conference on Simulation, Modeling and Programming Autonomous Robots (SIMPAR 2008)*, 2008.

[45] S. H. Kim and J. W. Jeon, "Programming LEGO Mindstorms NXT with visual programming," in *International Conference on Control, Automation and Systems*, Seoul, Korea, October 2007.

[46] N. Correll, C. Wailes, and S. Slaby, "A One-hour Curriculum to Engage Middle School Students in Robotics and Computer Science using Cubelets," in *Distributed Autonomous Robotic Systems*, University of Colorado, Boulder, USA, July 2014.

[47] M. Kandlhofer, G. Steinbauer, S. Hirschmugl-Gaisch, and J. Eck, "Children discover science: robotics, informatics and artificial intelligence in kindergarten and school." in *Workshop position paper at International Conference on Robotics in Education (RiE 2015)*, Yverdon-les-Bains, May 2015.

[48] H. Burgsteiner, "Design and Evaluation of an Introductory Artificial Intelligence Class in Highschools," Master's thesis, Graz University of Technology, Institute for Software Technology, Graz, Austria, 2016.

[49] V. Braitenberg, *Vehicles: Experiments in synthetic psychology*. MIT Press, Campbridge, 1984.

[50] M. Sipser, *Introduction to the Theory of Computation*, 3rd ed. Cengage Learning, 2012.

[51] A. Diekmann, *Empirische Sozialforschung*. Rowohlt, 2007.

[52] D. L. Jorgensen, *Participant Observation: A Methodology for Human Studies*. Sage, 1989.

[53] S. E. Hove and B. Anda, "Experiences from Conducting Semi-Structured Interviews," in *11th Software Metrics Symposium*, 2005.

[54] K. A. Neuendorf, *The Content Analysis Guidebook*. Sage, 2002.

[55] J. Corbin and A. Strauss, *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Sage Publications, 2014.

[56] P. Mabe and S. West, "Validity of self-evaluation of ability: A review and meta-analysis," *Journal of applied Psychology*, vol. 67, no. 3, pp. 280–296, 1982.

[57] M. Kandlhofer, G. Steinbauer, S. Hischmugl-Gaisch, and J. Eck, "A Cross-generational Robotics Project Day: Pre-school Children, Pupils and Grandparents Learn Together," *Journal of Automation, Mobile Robotics & Intelligent Systems*, vol. 8, pp. 12–19, 2013.

[58] N. Whitman and F. Jonathan, *Peer Teaching: To Teach Is To Learn Twice. ASHE-ERIC Higher Education Report No. 4*. ASHE-ERIC Higher Education Reports, The George Washington University, 1988.

[59] A. Anning and K. Ring, *Making Sense of Children's Drawings*. Open University Press, 2004.

[60] R. Reiter, *Knowledge in Action. Logical Foundations for Specifying and Implementing Dynamical Systems*. MIT Press, 2001.

[61] C. Maier, "YAGI - An Easy and Light-Weighted Action-Programming Language for Education and Research in Artificial Intelligence and Robotics," Master's thesis, Faculty of Computer Science, Graz University of Technology, 2015.

[62] A. Ferrein, C. Maier, C. Mühlbacher, T. Niemueller, G. Steinbauer, and S. Vassos, "Controlling Logistics Robots with the Action-based Language YAGI," in *IROS Workshop on Workshop on Task Planning for Intelligent Robots in Service and Manufacturing*, 2015.

[63] J. Craighead and J. B. R. Murphy, "Using the unity game engine to develop sarge: a case study," *Computer*, vol. 4552, pp. 366–372, 2007.

[64] S. Sardina and S. Vassos, "The wumpus world in IndiGolog: A preliminary report," in *Proceedings of the Workshop on Non-monotonic Reasoning, Action and Change at IJCAI (NRAC-05)*, 2005, pp. 90–95.