Final report

AI@Education: Teaching and learning at school with artificial intelligence tools

– Final report –

Commissioned by

Deutsche Telekom Stiftung

Presented by

Dr. Ulrich Schmid, Dr. Berit Blanc, Michael Toepel
(mmb Institut – Gesellschaft für Medien- und Kompetenzforschung mbH)

Collaborators:
Prof. Dr. Niels Pinkwart (German Research Center for Artificial Intelligence)
Prof. Dr. Hendrik Drachsler (DIPF | Leibniz Institute for Research and Information in Education)

mmb Institut GmbH
Folkwangstraße 1
D-45128 Essen

Phone: 0201 / 748509-94
Email: schmid@mmb-institut.de
Internet: www.mmb-institut.de

Berlin, Essen, Bonn, June 1, 2021

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Management summary

AI-supported learning technologies – i.e. solutions based on technologies such as machine learning, educational data mining or learning analytics – harbor enormous potential at every level of primary and secondary education: At the macro level (school organization), data mining and analytics can help optimize processes such as evaluation and planning. At the meso level (classroom teaching), AI can enable new methods of assessment, grading, tutoring and classroom management. At the micro level (learning process), smart learning applications open up tremendous new possibilities by allowing more personalized learning formats and assistance systems as well as automated predictions, performance assessments and learning recommendations to be implemented.

This technology can benefit students, especially those with special needs. However, smart assistive systems can also help school administrators and particularly teachers in many ways by supporting them or performing some of their tasks in schools and classrooms. Ideally, it will also free up teachers to focus on supporting individual students.

At the same time, empirical education researchers and learning theorists have repeatedly expressed their doubts about the promise of AI-based learning technologies. Their criticisms often revolve around the didactic systems underlying allegedly “smart” learning applications; the paucity of research into the alleged impacts of AI-based applications on educational outcomes; and the general absence of any evaluations about the potential applications (such as automated assessments and grading). Finally, there is an urgent need to consider the ethical and data privacy implications, especially in primary and secondary education.

AI, it must be acknowledged, is a kind of “base technology” found in almost every modern educational technology solution, from learning platforms and educational clouds to collaboration tools or even self-study software in all its varieties. AI is never a standalone application but is always integrated into a growing variety of devices, systems and applications. A review of the supply and market situation revealed the following trends:

a) In addition to the “smart” features and functions being developed in virtually all modern-day education solutions, the primary and secondary education market has witnessed the introduction of a growing number of explicitly AI-based products such as speech-based tutoring and assistant systems, adaptive learning software or applications for automatic assessment, grading and scoring.
b) Research and product development activities in the US, China and Israel[1] have been quite dynamic. Europe is falling behind, while Germany has only a few isolated research projects and market-established applications in this field.
c) An estimated one third of the AI-based education applications investigated in this study are still in the development stage.
d) Most of the established products target the large after-school market, i.e. tutoring and self-study. These applications combine a personalized, adaptive learning experience with appropriate exercises and analysis functions and thus promise to make learning more

[1] The Israeli government’s activities in AI and education, though not investigated further in this study, have been stepped up considerably in recent years and should not go unmentioned: A good overview is available here: https://www.mop.education/wp-content/uploads/AI-in-education-lab-a-summary-0920.pdf

efficient, especially for subjects that rely on "rule-based learning" such as STEM classes and language learning.

e) AI solutions are currently underutilized in classroom and school organization in particular. In the future, applications will likely be developed for concept-based learning as well as segments outside of purely cognitive abilities (i.e. meta-cognitive, social, communication and emotional skills).
f) Research is particularly needed with regard to didactic considerations, learning effectiveness and the not inconsiderable ethical and legal challenges of extensively utilizing and analyzing data in learning processes.
g) In addition to the unresolved data privacy and data security issues, the problem of biased data and biased algorithms – i.e. inadequate data resources that produce defective AI algorithms – in the field of learning will have to be addressed as well.

The experts surveyed in this study were rather restrained in their assessments of the various AI scenarios in education, largely due to the obvious discrepancy between promises and reality. This is particularly true of the more ambitious AI scenarios in the school setting. Some of the core AI visions for primary and secondary education, including personalized learning and virtual assistants, enjoy broad support from the respondents but consistently inspire doubts about their technical feasibility and evidentiary basis. Other visionary AI ideas, particularly those relating to automatic grading and forecasting (i.e. predictive analytics), are viewed as neither technologically feasible nor pedagogically desirable.

This study concludes with four strategic recommendations for the future:

1. **Educational innovation process with room for experimentation:** Given the fierce competition with Chinese and US learning technology providers, Germany should invest more not only in research and (product) development but also in trialing these technologies and "grounding" them in the day-to-day realities at German schools. To advance that goal, this study's first recommendation is to drive didactically oriented innovation processes and create new space and opportunities to experiment with smart applications. This could be done by establishing special "AI innovation schools", for example.
2. **Establish co-teaching and assisted learning as core strategies:** One key argument for using AI-based applications in schools is their largely "assistive" function. AI technologies will predictably be embraced and accepted wherever they can effectively, reliably and cost-effectively help teachers handle their expanding workloads without violating data privacy laws. This trend will only accelerate amid the growing teacher shortage. Education scholars also broadly agree that AI systems should support and supplement teachers in face-to-face learning settings, not replace them (co-teaching and assisted learning in hybrid learning arrangements and flipped classroom settings, etc.).
3. **Drive the further development of AI-based applications by providing secure data resources ("data lakes"):** Perhaps the most important issue relates to how data is used to develop and apply smart solutions. One the one hand, self-learning AI procedures are and will remain highly dependent on having access to sufficient data resources for machine learning. On the other, these applications will only be accepted, particularly in schools, if they follow secure, reliable and ethically sound rules and procedures. One way to accomplish that is by setting up "data lakes",

i.e. relevant, but anonymized and pseudonymized, test data stocks for developing future AI algorithms for the edtech sector.

4. **Broaden teacher training and establish AI as a classroom tool:** Being a future base technology, AI urgently belongs in school syllabi and specialized classes. At the same time, teachers must be trained, whether in their initial programs or through continuing education, to think (critically) about AI-based learning technologies and use them in an educationally appropriate manner. The goal is to develop the competency to use these technologies effectively even as algorithms increasingly permeate learning and educational processes. This environment will actually demand higher pedagogical standards, not lower ones.

If the market and trend analysis in this study is placed alongside the current scholarly debate on the challenges of using AI in school settings, it suggests that more and more AI components will be integrated in media, tools and platforms used for digitally supported learning and teaching in schools in the years to come. While there will be standalone applications with limited scopes (e.g. for language learning or school management), two broader technological focus areas could develop: a) the smart learning cloud as a highly available infrastructure with counterparts at the state, district or individual school level, and b) the “learning companion”, an always-available personal learning assistant.

1 Introduction – the issues

Soccer fans who tune into TV broadcasts or open soccer apps have long been inundated with extensive statistical analyses of possession times, distances run, passing percentages and goals. However, today's tracking and measurement tools enable far more detailed analyses of statistics such as speed of attack, passing accuracy, kicking angle, respiratory rate and fitness – all of which are constantly being tracked and recorded. No coaching team, no matter how attentive it might be, could constantly capture and evaluate so much information. However, this feat is possible through video monitoring, wearables (sensors worn on the skin) and automatic facial recognition: Smart systems "recognize" the behavioral patterns and performance profiles of individual players and entire teams. That allows not only nuanced assessments of the quality of tackling or positional play but also data-driven forecasts and decision-making tools for training plans and game-day decisions. Indeed, strategic decisions such as player transfers are now relying on input from AI, i.e. from comprehensive algorithmically generated performance analyses.

What startups like SkillCorner or AiCOACH have successfully done for soccer and other sports is now making headway into the educational sector. After all, why shouldn't something that works in athletic coaching also help learning processes in primary and secondary education? Chinese schools in particular have long been experimenting with face and speech recognition systems as well as wearables for measuring experiential data such as body temperature, brainwaves, heart rate, eye and body movements, etc. in order to draw conclusions about attentiveness, comprehension problems and concentration difficulties or to predict future school performance or test scores (cf. videos such as https://www.youtube.com/watch?v=JMLsHI8aV0g).

Similar experiments are also running in Germany. One of them is Hypermind, a project conducted by the German Research Center for Artificial Intelligence (DFKI) and Technische Universität (TU) Kaiserslautern. It has developed an intelligent textbook that tracks and analyzes students' eye movements in order to identify learning difficulties and personalize the learning process (i.e. "adaptive learning"). Tutoring company GoStudent has taken a similar route in its efforts to improve students' learning experiences by using an AI tool (known as "iMotions") that analyzes facial expressions.

Obviously, these kinds of analyses require extensive (comparative) data about the students and their behaviors, interactions, communications, facial expressions, etc. Large quantities of this data are produced when using digital and mobile learning technologies: It is very easy to track metrics such as clicks, navigation patterns, time spent on each page, number of repetitions, difficulty levels, text inputs and search queries, not to mention the results of online tests as well as explicit evaluations, performance assessments, etc.

As with soccer training, not even the most attentive teacher could capture, let alone analyze, even a fraction of this data through close observation alone. All the automatically generated data goes into complex statistical analyses and serves as the foundation for intelligent self-learning algorithms (i.e. machine learning) that power innumerable applications and services related to learning processes at the primary and secondary school level. It is these tools that we examine on the following pages. Three questions guide our analysis:

1. What **opportunities** are generally associated with AI in primary and secondary education?
2. What **providers and applications** have positioned or established themselves in the market?
3. What **challenges**, and perhaps risks, counterbalance these opportunities and how can they be strategically addressed?

The findings of this study are highly relevant, particularly in the aftermath of the COVID-19 crisis and the resulting acceleration of school digitalization. It has thus become even more urgent to determine whether modern – which almost always means AI-based – education technologies can help address the current challenges surrounding educational equity, heterogeneity and support for disadvantaged children. This report describes examples and applications that strive to achieve that very goal: to employ intelligent, adaptive systems in order to improve learning at schools and generally enable learning processes that better reflect children's individual needs and abilities.

However – as the sports analogy makes abundantly clear – intelligent systems can support use cases that reach far beyond the individual learning process. For entire classes and small groups within classes, smart applications such as digital assessments, automated grading, performance data evaluations and recommendation systems can provide new and perhaps more direct forms of educational feedback in more or less real time. And what the automatically generated personal training plan is to sports, the adaptive learning path is to education: both rely on data resources that extend beyond the information horizon of the individual athlete/student and coach/teacher.

Finally, AI systems can enable novel use cases for schools as institutions, such as "automatically" generating evaluations and reports for the local school board as well as diagnoses and forecasts for school management purposes (staff, resource and room scheduling, etc.). While this field is very important, it is often overlooked and could be a rich source of untapped technological opportunities for improvement and streamlining.

In an effort to present an objective, evidence-based assessment of AI-based learning technologies, this report not only covers the potential applications and market and technology trends but also looks at the risks and strategic development prospects.

2 Definitions: intelligent learning technologies and AI in schools

The purpose of artificial intelligence is, as former DFKI director Wolfgang Wahlster puts it, "to model intelligent behavior in computers in order to provide physical or cognitive assistive functions for people". AI is embedded in almost all modern IT systems in our connected work and home environments, he stresses, from industrial control systems or navigation apps to search engines, social media, smart toothbrushes or refrigerators. AI is thus a base technology; there is, as Wahlster notes, "no system that consists solely of AI components". (Scheer, 2018: 7)

As we will see, this is particularly true of digital education technologies. Many modern-day school administration, planning and learning systems already have smart features. They include learning platforms that automatically generate various "views" of students' and teachers' profile and performance data; school management systems that aggregate data on room and resource use, absences and substitute teaching arrangements and then suggest schedules based on that data; and learning applications that generate personalized learning recommendations based on completion times or test scores.

While these are clearly "cognitive assistive functions", some of today's AI researchers may hesitate to call these applications "intelligent". According to the current state of artificial intelligence research, AI is not solely about providing assistive functions but rather "the ability to model and replicate human thinking, decision-making and problem-solving behavior … using computer-aided processes" (Bendel, 2020: 59). In other words, intelligent devices or applications should be just as adept at learning as people and should generate independent diagnoses and make decisions on the basis of what they have learned. In primary and secondary education, AI systems could, say, comparatively analyze the competence of a student, small group or entire school and provide targeted recommendations to whoever is responsible for acting on this information, be they students, teachers or other decision-makers.

What is artificial intelligence?

Starting in the mid-1950s, the term "artificial intelligence" referred to a research area in the still-young field of computer science. The term was chosen in the hopes of conferring on computers abilities that would make them appear "intelligent", such as carrying on a conversation or translating a text into another language. Since the concept of human (biological) intelligence is already vague and lacks a generally accepted definition, it comes as no surprise that all efforts to come up with a generally accepted and sufficiently inclusive definition of AI have failed as well. To make matters worse, AI is currently a catch-all term that encompasses not just the broad research field, but also technologies (from expert systems to machine learning) as well as systems and applications (e.g. autonomous vehicles, smart assistants or recommendation systems). However, even these segments have borne witness to definitional debates. For example, experts disagree on whether AI should only include learning systems, as is often the case. Also, when applications generally consist of a multitude of components, it is next to impossible to say where "mere" digitalization ends and AI begins.

Machines' "intelligent" behavior clearly includes the abilities to perceive (visually), detect patterns, simulate independent learning, make decisions and predictions, independently solve problems, recognize speech and faces and arrive at (logical) conclusions (cf. de Witt, Pinkwart, Rampelt 2020).

2.1 AI applications in primary and secondary education

Due to the ambiguity of the term "artificial intelligence", it may be helpful to focus a bit more on concrete AI applications instead of the abstract definition of the term. The following figure, for example, contains some of the AI technologies frequently mentioned in connection with primary and secondary education.[2]

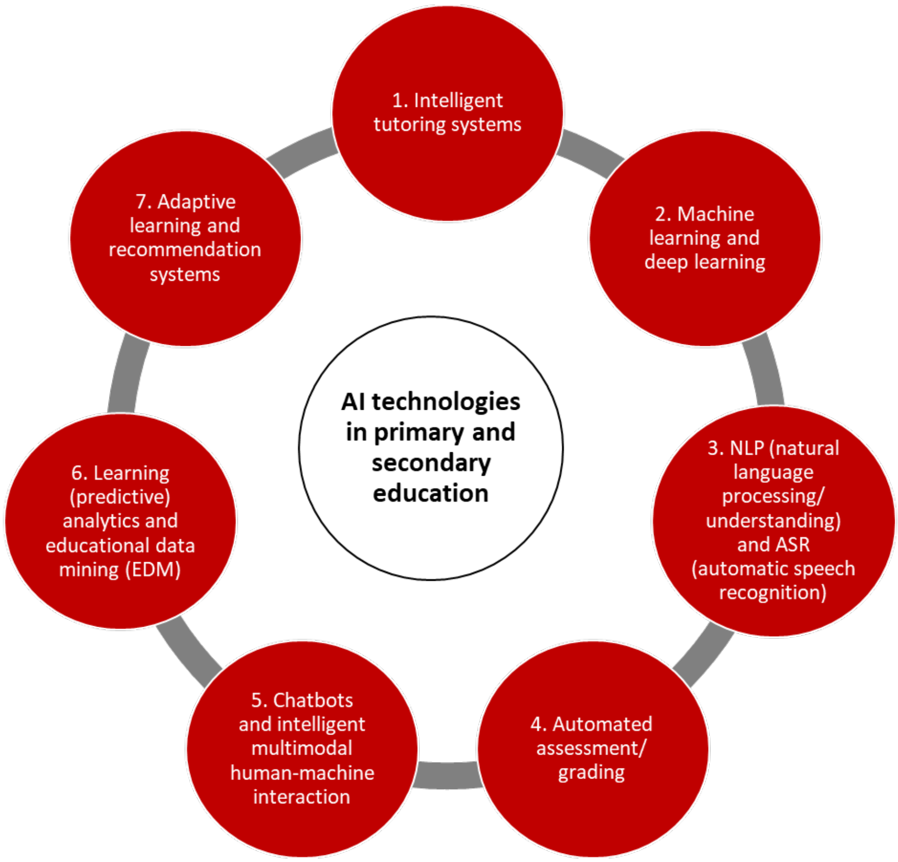

Figure 1: AI technologies commonly mentioned in connection with primary and secondary education

Let us briefly consider these technologies one by one:

[2] It should be noted that the terms and technologies mentioned here belong to completely different categories. Fundamental AI processes such as machine learning or data mining are listed alongside practical applications such as chatbots or automated grading. Nonetheless, this grouping should largely serve as a clear overview of the AI-associated technologies found in primary and secondary education.

1. Intelligent tutoring systems

Intelligent tutoring systems (ITSs) combine human communication and interaction formats (e.g. natural language, chatbots) with machine learning, learning analytics and educational data mining processes. It takes large, high-quality data resources to recognize learning patterns and perform all the subsequent decision-making, forecasting and recommendation processes that other "intelligent" services are known for (e.g. shopping and dating platforms or navigation systems). Systems have to know and analyze not just an individual student's data, but also the competency profiles of as many other students as possible with similar qualifications, the same age or gender and comparable performance profiles and learning objectives, etc. in order to generate useful conclusions about a student's individual training needs as well as reliable didactic assessments and assistance. High-reach services with (hundreds of) thousands of users (such as MOOCs) are at a clear advantage.

2. Machine learning and deep learning

Current technological trends are being driven by machine learning and one of its subsegments, deep learning. In both these technologies, an artificial system learns from examples and can extrapolate generalizations from them once the learning phase is done. Algorithms develop a statistical model based on training data. In other words, instead of simply memorizing the examples, the system detects rules and patterns in the training data. It can then evaluate unknown data (i.e. learning transfer) or, alternatively, fail to learn unknown data. Machine learning methods are often used for classification and forecasting tasks and employed either to support decision-making or automatically control processes.

Machine learning breaks down into three types of learning algorithms: supervised, unsupervised and reinforcement learning[3]. In supervised learning, the initial data used to train the system is already labeled (all cat pictures are labeled with "cat" metadata). The algorithm then uses this data to sort similar things into taxonomically correct categories. In unsupervised machine learning, the information fed into the system is not labeled with metadata. The AI then has to identify typical patterns of characteristics independently and categorize the data accordingly. This was done to program the chess and go programs at Google's DeepMind subsidiary, for example.

Most of the data used for machine learning in education is generally personal data (such as individual achievement data, class grades, test grades, etc.) that requires particularly high levels of data privacy and data security.

3. NLP (natural language processing/understanding) and ASR (automatic speech recognition)

ASR and NLP/U applications enable text or speech-based conversations and interactions that approximate the quality of standardized information-driven discussions between humans – and may even improve on them by logging, analyzing and potentially emailing conversations and information. In NLP/U, a computer system uses AI to process natural spoken language or text, identify individual words and parse the meaning of entire sentences or phrases, including their tone and context. Examples include online customer service chatbots (for text input) or voice assistants such as Siri or Alexa. They use NLP/U to "understand" spoken language and either select an appropriate answer from a database or generate specific answers in a manner that imitates human conversation. In addition, translation tools like Google Translate or DeepL use NLP/U to analyze large online corpora of foreign language texts and translations as well as corrections that human editors submit in order to constantly improve the automatically generated translations. Intelligent chatbots or voice assistants represent – especially in the education sector – a highly attractive, low-threshold interface

[3] In reinforcement learning, the AI makes adjustments in response to positive or negative reactions to its actions.

to students that can be used in various ways for language learning and to look up answers to knowledge-based questions in a given situational context.

4. Automated assessment/grading

Automated assessment and grading is considered supervised learning. Marked training data is fed into a learning algorithm so that the algorithm can reliably identify the correct solution to a problem and give the student appropriate feedback and/or an appropriate grade.

5. Chatbots and intelligent multimodal human-machine interaction

Chatbots are communication tools that represent one example of human-machine interaction. The core elements of efficient communication are the operating concept (software and ergonomics) and the interface technology, i.e. the communication interface between the software and the human user. Communication can assume a wide variety of forms, from text entry to speech recognition (cf. Denk, Khabyuk 2019).

Intelligent multimodal human-machine interaction refers to the "analysis and 'comprehension' of language (in conjunction with linguistics), images, gestures and other forms of human interaction" (German Federal Government 2018, supplement from Christian Dufentester; also cf. Mah & Büching, 2019).

6. Learning (predictive) analytics and educational data mining (EDM)

Learning analytics refers to the constant measurement, collection, analysis and reporting of data on students and their activities in order to better understand and optimize learning in the various digital learning environments. Wherever learning management systems (LMSs), MOOC platforms, social media or other digital tools are used, clicks, navigation patterns, search queries, exercise and test completion times and the quantity and quality of interactions and communication activities can be documented and analyzed against competency and achievement levels. Information resulting from the use of learning applications can be supplemented with data generated by sensors or video cameras such as eye and head movements, vital signs (heart rate, blood pressure), facial expressions (expression analytics), brainwaves, etc.

This data basis can be used to generate didactic interventions and incentives as well as personalized learning paths, assistance and learning objectives. The overall objective of learning analytics is thus to enable personalized learning and provide reliable forecasts of future academic achievement (predictive analytics).

Educational data mining (EDM) – including machine learning and statistical procedures – is used to measure and analyze test scores as well as learning processes, learning activities, learning times and learning durations in order to obtain insights into how students learn in certain teaching formats or with certain learning programs and systems. EDM thus helps drive the development of learning theories in educational psychology and educational studies. While EDM is mainly about analyzing student data in order to optimize learning settings, systems, services, tools and organizations, the closely related field of *learning analytics* focuses more on the students themselves.

7. Adaptive learning and recommendation systems

Adaptive learning refers to intelligent teaching methods that allow learning tasks and resources to be presented in such a customized fashion that they meet the student's individual needs (abilities, competencies, expectations, etc.) as effectively as possible.

Adaptive learning settings automatically present lessons (exercises, tests, etc.) that, judging from certain indicators (e.g. academic achievement, competency level, test scores, academic performance, learning objectives), are appropriate for the student's needs, are the right level of difficulty and appear in the right order. The class should be neither too challenging nor too easy for students. In an ideal scenario, students are assigned the learning programs that suit them best and thus stay as motivated as possible.

Adaptive learning requires the student's individual performance and learning profile to be understood roughly as well as good teachers do. However, since it is neither possible nor reasonable to expect to obtain this level of understanding solely by holding repeated tests and performance assessments, learning outcomes have to be constantly analyzed using various metrics (e.g. learning duration, degree of difficulty, activity level) at the smallest knowledge unit level (i.e. performance assessments) in order to understand learning behavior in detail. Learning analytics covers methods from various disciplines such as computer science/AI (graph theory), psychometrics, statistics (inferential statistics), education, psychology and brain research.

Recommendation/recommender systems are used in digital education settings to suggest more advanced learning activities or offerings tailored to the learner. These suggestions are as precise as possible and based partly on past preferences and assessments and partly on analyses of similar learning or student situations. Examples from other domains include playlist suggestions on platforms like YouTube, Spotify or Netflix or shopping recommendations on online marketplaces. Recommendation systems improve in accuracy as more information is accumulated about individual learning behavior and comparative statistical analyses are conducted of large data resources on similar users. Like most AI systems, recommendation systems rely heavily on *machine learning* processes. Machine learning can extract patterns from very large datasets and constantly analyze the accuracy and success rate of past recommendations. For example, AI-based recommendation systems learn when recommendations are accepted or rejected and can thus adapt future recommendations as well as the weight assigned to certain information.

2.2 Three application levels for AI in primary and secondary education

The aforementioned technologies currently have the potential – in various combinations and variations – to permeate and change all key areas in primary and secondary education. Their impact is by no means limited to teaching and learning, no matter how much the public debate may focus on those exact processes. Schools are complex institutions in which knowledge transfer processes are extensively designed and planned, organized and administered, communicated and evaluated. All areas of activity are heavily influenced by technology today – and are thus open to AI innovations. In this study, we distinguish between three areas or levels of application:

1. The micro level of individual learning and practicing.
2. The meso level of teaching and testing in small groups and classes.
3. The macro level of managing, evaluating and planning schools in their capacity as organizations and systems.

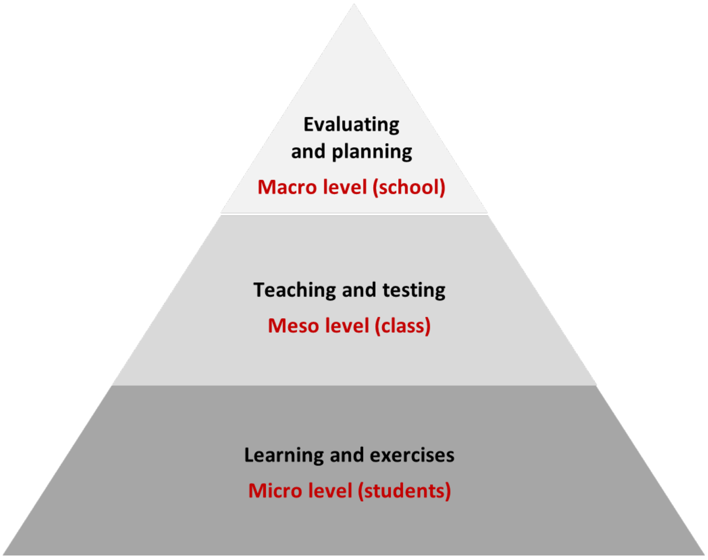

Figure 2: Possible areas of application for AI in primary and secondary education

“Smart” technologies are being used in all these areas to support complex, fully or partially autonomous management, decision-making and forecasting processes and thus tap latent didactic and organizational potential.

First, let us consider the **micro level**. It encompasses all the activities and forms of individual knowledge acquisition and learning.

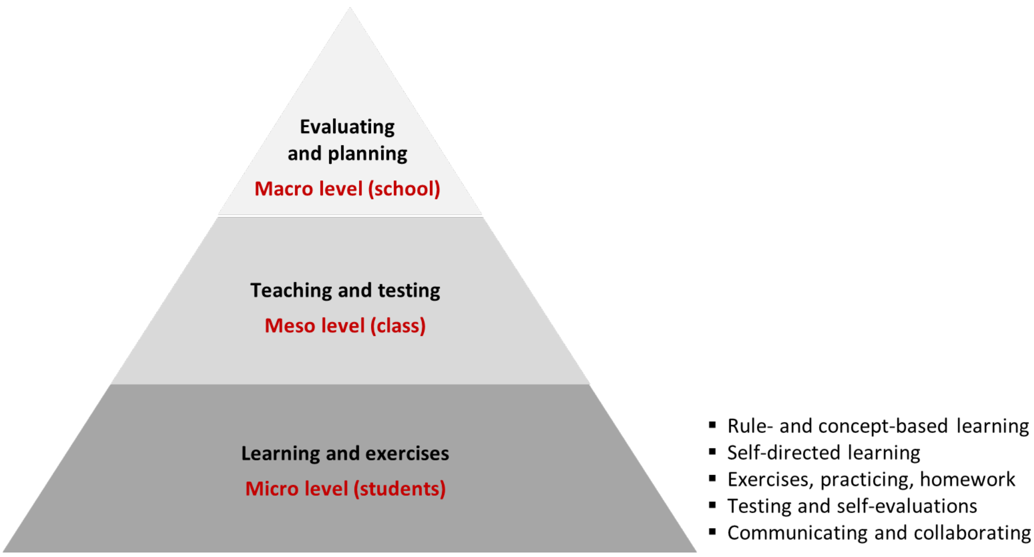

Figure 3: Application areas for AI@School: micro level

In this segment, for example, smart data analyses can be used to extensively monitor, document, statistically analyze (i.e. learning analytics) and compare (in performance assessments) students’ learning behavior in collaboration networks or digital learning environments (also known as learning platforms). The strengths, weaknesses and learning patterns uncovered in these analyses can go into nuanced competency and performance profiles as well as personalized learning tasks and exercises (i.e. adaptive learning, recommendation systems). They also enable forecasts of likely academic achievement and suitable educational focuses (i.e. predictive analytics). Interactive and multisensory learning and exercise programs (e.g. augmented and virtual reality) as well as intelligent tutor systems can also give rise to novel methods for transferring knowledge and "automatically" assisting students in many subjects. Their main promise is the ability to support individual students.

The **meso level** of teaching classes or small groups encompasses all methods for testing and transferring knowledge and for generally organizing and supporting learning processes.

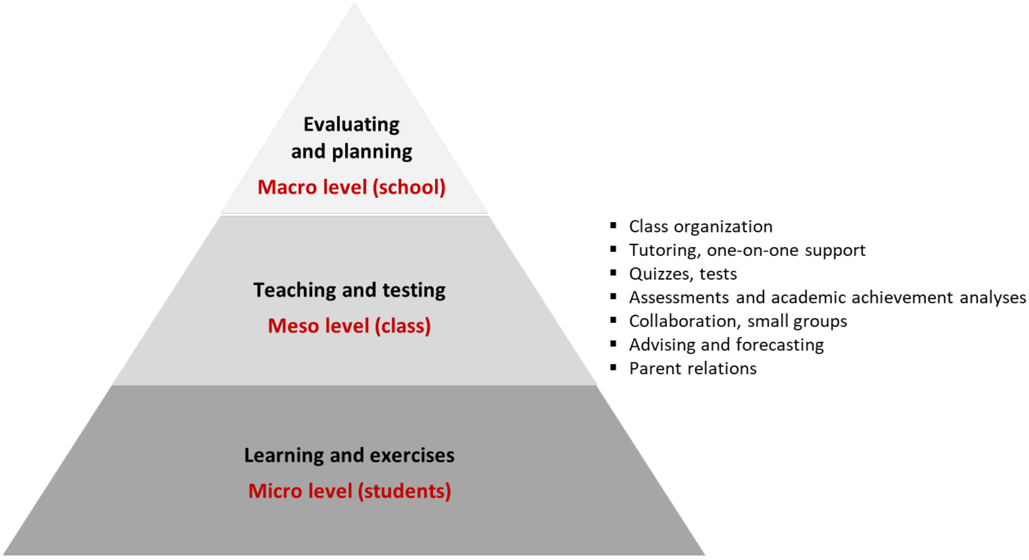

Figure 4: Application areas for AI@School: meso level

In this segment, virtual assistants equipped with speech recognition functionality such as Alexa or Siri and paired with state-of-the-art sensors can enable human-like communications and interactions with machines or media (smartphones, humanoid robots, chatbots, etc.). As a result, they can correctly interpret natural language (natural language processing – NLP), gestures or even facial expressions. These types of assistant systems increasingly serve as virtual teaching assistants or tutors (as in intelligent tutor systems – ITSs) and can answer or respond appropriately (i.e. visually, textually, in spoken/audible form or with facial expressions) to factual questions in specific contexts for students at various learning and knowledge levels. They can also find and provide material appropriate for the student's current academic achievement level from an ever-growing repository of digital learning tools and services.

In addition, smart assistants can lighten teachers' testing workload by automatically assessing and grading knowledge and academic achievement in various examination formats (standardized tests, essays, presentations, etc.) and can forecast future achievement (i.e. predictive analytics) and then recommend interventions for teachers.
AI can also support the implementation of existing syllabi. Curriculum frameworks generally describe the required competencies to be fostered for each class and grade level and link the outcomes to content that students are required to learn. Syllabi could be tied to tracking data generated from students' individual learning processes. The AI could then "detect" events in a student's learning process and classify them as positive or negative based on the learning outcomes in the syllabi before suggesting appropriate interventions.[4]

[4] Data cannot currently be linked to outcomes in Germany since computers are not used for learning at some German schools and the data is not currently (allowed to be) collected. However, some efforts have already begun. The longitudinal studies from the KESS project and other achievement tests provide relevant data lakes that can be used, with support from AI, to develop models for positively or negatively predicting academic achievement (as they relate to the above requirements).

Finally, the **macro level** of schools and school organization mainly revolves around planning and management processes.

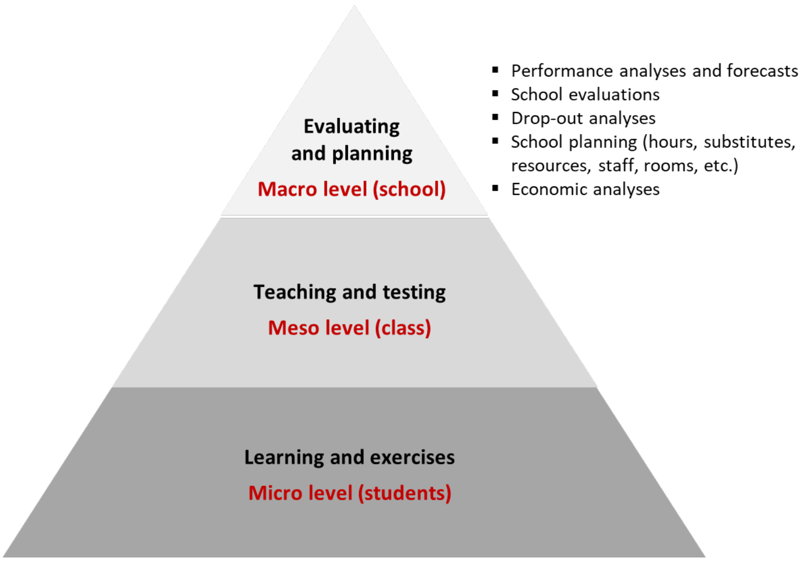

Figure 5: Application areas for AI@School: macro level

Outside of purely "pedagogical" considerations, AI systems can effectively support the school organization process – i.e. management and planning – by enabling comprehensive comparative evaluations of everything going on in classrooms, schools and school systems as a whole (i.e. educational data mining). These kinds of AI-based management systems are far more efficient at diagnostics and prediction with respect to various metrics and indicators such as absences, substitute teaching times, staffing, resources or competency and achievement levels. This not only improves organizational transparency but enables recommendations to be generated for school administrators, teachers and students and supplies data to support performance reviews, school inspections, school development consultations, et cetera.[5] In addition, sensor data and video recordings can help in evaluating students' individual and collective learning patterns (regarding activity, concentration, movement, communication, etc.) in the learning and teaching process and in gaining pedagogical and organizational insights (for parent-teacher conferences, assembling small groups, etc.).

2.3 AI: a problem solver?

AI-supported applications in primary and secondary education will not only support individual students' learning processes but can also lighten the workloads of teachers and school administrators. They can effectively support almost all the tasks entrusted to a school system that is currently staggering under enormous pressure to meet current requirements. This section recapitulates AI's ability to help tackle today's core challenges in primary and secondary education.

[5] Cf.: https://datafied.de/ueber-das-projekt/teilprojekt-1-schulaufsicht-und-schule/.

Challenges in primary and secondary education	How AI-based solutions can help
Growing heterogeneity of the student body (in terms of academic achievement, language levels, special needs, socio-cultural differences, etc.) and the special need for support and remedial education due to the COVID-19 pandemic.	Learning analytics and education data mining can be employed to more quickly identify and forecast individual achievement and concentration levels as well as cognitive and motivational problems. AI can yield personalized, auto-curated learning programs and recommendations. Students can communicate in various natural languages with personal virtual tutors and intelligent assistants (e.g. chatbots, learning companions) at any time or place. Adaptive self-study learning tools (learning software, test trainers, apps, learning games, video tutorials, etc.) can be used to support individual students in addition to regular classroom instruction, especially in STEM and language learning classes.
Growing teacher workload alongside worsening staffing shortages (especially in STEM classes).	(Partially) automated assessment/grading and intelligent testing systems reduce the amount of effort spent on assessments and grading. Assistive tutoring systems support collective learning and teaching processes in small groups and full classes. In-class learning applications enable flipped classroom settings and allow teachers to spend more time and energy on one-on-one coaching and advising in class. AI teaching assistants can assist teachers with all the administrative tasks related to class organization and reporting. Smart learning and collaboration platforms make it easier to set up collective learning, virtual teaching and home schooling scenarios.
New subjects and learning objectives	Subject-specific learning software and learning companions enable self-study phases that supplement classroom teaching. Intelligent collaboration platforms allow classes and schools to collaborate with one another and share educational materials.
Growing administrative effort required in school organization (evaluation, digitalization, school oversight, communication, parent relations, scheduling, etc.)	Modern school management and information systems analyze and diagnose rich stocks of school data (educational data mining), generate automatic forecasts (predictive analytics) and assist with all the planning and administrative work involved in school management. Assistive information and communication systems (chatbots, virtual assistants, etc.) support school administrators in interactions with students and parents.

3 Market analysis

The aim of the market analysis was to provide an initial systematic overview of offerings that are "intelligent" in the stricter sense, i.e., AI-supported, and that are also available as products in the market. What do they aim to do, and in which areas and levels (micro, meso, macro) are research and development activities particularly intense? These questions underpinned a web and literature search, and the applications found in the search were logged in an Excel overview (i.e. the "long list"). The search covered German- and English-language websites and texts. However, these findings offer neither a complete nor a representative picture of all AI technologies available for schools in global markets. Instead, this market analysis should be understood as an initial organizing review and overview of a highly dynamic field.
The basis for recording the applications was a category system comprising descriptions, providers, activities and other categories. For example, the long list was filled not only with the application's provider, name and a brief description of the application but also the country of origin as well as AI components (e.g., emotion recognition, speech input and output) that were either specified or assumed based on the functional description (see the annex for a more detailed presentation of the category system). Furthermore, a central task in the search was to assign the application to a broader application area: learning, teaching or organization.

3.1 Global results of the search

All told, 99 applications were identified and logged. More than half came from the US and China (cf. Figure 6). The US and China's clear development and product lead can be explained, among other things, by the technological strengths of their national IT industries (e.g. Silicon Valley as the long-standing global digital technology driver). However, cultural differences also play a role. Individuality and privacy are less important in China than in Germany, where strict data protection requirements and concerns slow down development and application. In addition, digital computing education in China begins early, in preschool. In Germany, by contrast, early media literacy education and the use of digital media in daycare centers and elementary schools are hotly debated topics (cf. Nieding/Blanc/Goertz 2020).

Nevertheless, Germany still ranks third as the origin of 13 offerings, i.e. just over one tenth of the applications searched. However, conducting a targeted web search in Germany and scanning based exclusively on German- and English-language websites and publications can yield distorted results: Applications from Scandinavian countries, which are highly advanced in school digitalization, do not appear here on account of the language barrier. Therefore, it is implausible to place Germany among the top 3 countries worldwide for AI-supported offerings for schools.

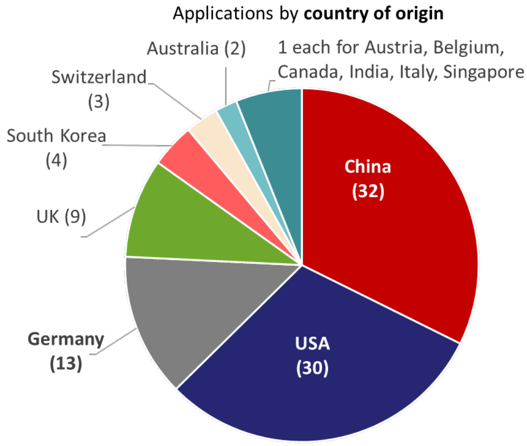

Figure 6: Origin of the 99 AI applications searched

Chinese offerings, on the other hand, are mentioned particularly frequently in the English-language literature. AI education solutions are very common in Chinese companies and increasingly in schools. As guest researcher Min Zhang reported in her interview for the study – and as the experts confirmed – China is undergoing four trends:

(1) The Chinese market contains many very similar applications as well as
(2) platforms for schools as a whole (e.g. iFlytek, Baidu).
(3) The most widespread offerings are in the after-school and tutoring segment (e.g. Squirrel). They include AI to support the learning and teaching of English, computer science and artificial intelligence (English: Liulishuo, VIPKID; programming and robotics education: Codemao, UBTECH, rainier).
(4) Government funding has encouraged AI to spread more and more in schools. Most of these AI-based applications target the macro level, especially for school management, or the meso level, e.g. for observation and cloud-based assessment of learning behavior (e.g. HIKVISION: class behavior management system: face and emotion recognition in classroom recordings).

However, the story is somewhat different across multiple countries (cf. Figure 7) and can be summarized as follows:

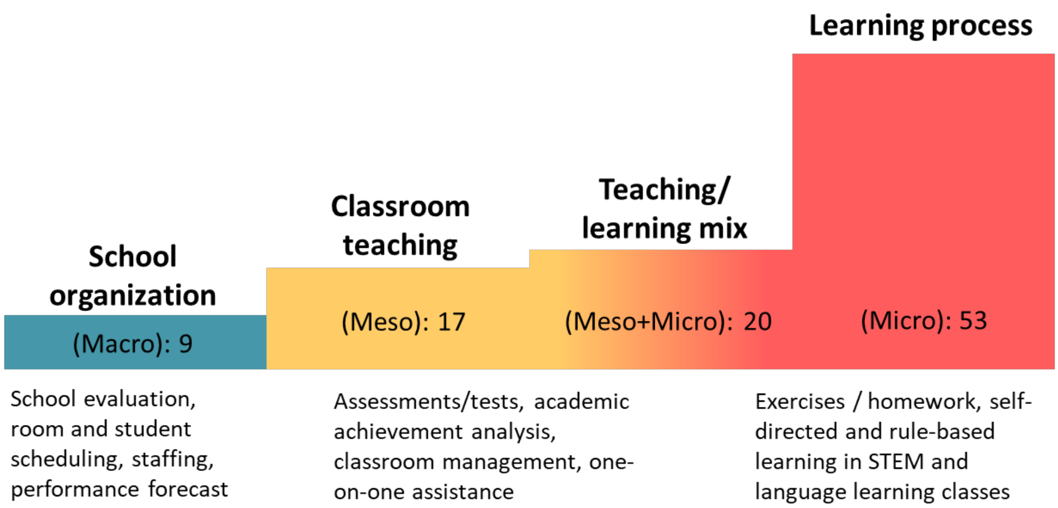

Figure 7: Distribution of the 99 searched applications at micro, meso and macro levels

- AI-based applications that specifically target the macro level, e.g. evaluating and managing schools, have been rather rare. However, this area will likely see more intelligent features and functions integrated into established system solutions in updates and upgrades.
- Around half of the 99 applications searched focus on self-study (micro level) and mainly target the after-school market.
- This group is dominated by applications for subjects that rely more on “rule-based learning” (i.e. show, explain, practice; assignment type: correct or incorrect), i.e. mathematics, STEM subjects, foreign language learning.
- Applications for “concept-based learning” are still in the developmental stage (i.e. logically thinking things through, making connections, developing insights, complex and open-ended assignment types).
- About one third of the applications searched are still in the early development and product stage.

Finally, an evaluation of alleged or presumable AI components – many offerings provide no explicit or reliable information at all – shows that AI technologies (such as machine learning, learning analytics, educational data mining, natural language recognition, etc.) are functionally integrated into almost all modern learning and education solutions. Explicitly standalone AI solutions or products are essentially non-existent in the market.

3.2 Application examples: the typical and the special

To illustrate the above breakdown of possible AI applications in schools into micro, meso and macro levels and gauge possible market trends, the following section presents five profiles of typical areas of application. The applications were chosen for their innovativeness, transferability and applicability to the German school and education system. **This is not intended to be an exhaustive product analysis.**

The **micro level** is represented by two applications; both mainly support mathematics education but are increasingly branching out into other subjects: **Squirrel AI Learning by Squirrel** represents personalized after-school tutoring and is very successful in the Chinese tutoring market. **Bettermarks** is the most widely used application in Germany and has been rather reluctant to use AI components.

For the (predominant) **meso level**, we present **Pearson’s Knowledge Analysis Technology (KAT)**, an essay scoring technology, and **iFLYTEK**, a platform for language teaching.

Finally, for the **macro level**, we selected **IBM’s Watson Education Classroom** to represent a multifunctional cognitive system for schools.

MICRO LEVEL EXAMPLE I: Squirrel AI Learning – Personalized After-School Tutoring: tutoring market

Personalized learning and tutoring with AI-based real-time feedback and personalized tutoring for students in various subjects

Description
Squirrel AI extensively uses and refines its learning analytics and adaptive learning components and gains significant momentum from its considerable market success and growing pool of available learner data (granularity and scalability). Development teams work with teachers to break down each offered course into the smallest possible conceptual pieces (learning nuggets). Middle school math, for example, is broken down into 30,000 atomic elements or "knowledge points" such as rational numbers, the properties of a triangle, and the Pythagorean theorem. The goal is to diagnose as accurately as possible any areas that a student may not understand.

Relevance
Squirrel AI is one of the most successful products whose reputation has been solidly established by very successful marketing and the use of adaptive learning (with over 2,000 centers nationwide). Squirrel AI provides learning materials and tests in almost all learning domains for primary and secondary schools. The company is currently looking to expand beyond tutoring and move into schools.

Similar examples found by the search
Somewhat comparable in Germany: Bettermarks (no. 15) SofaTutor, Serlo, Scoyo, various video channels, and others are successful in the after-school market but do not yet appear to use AI components.

Sources
Squirrel: no. 45 in the search list
Company website: http://squirrelai.com
Software and company media coverage:
https://www.freitag.de/autoren/the-guardian/schoenes-neues-lernen
http://secinfinity.net/china-begann-mit-kunstlicher-intelligenz-statt-mit-lehrern-zu-unterrichten/
https://www.heise.de/hintergrund/4-4616136.html

Squirrel's CEO promoted his product at an international startup and investor conference as follows: "Powered by AI technology, the learning engine is used to solve many problems in China's traditional education industry, such as the uneven distribution of educational resources and the low learning efficiency of students. AI education will eventually grow into personalized education and provide every student with a learning solution and an AI expert teacher of his own."[6]

This example illustrates the importance of the after-school market as a driving force for the development of forward-looking applications in the school market. As standardized tests increasingly determine curricula and teaching and universities grow more selective about admissions, the tutoring market will become more relevant and companies will have greater incentives to develop and offer AI-based products.

The Chinese market is the clear trailblazer, after South Korea, Singapore and Japan. Comparable dynamic developments have not yet occurred in Europe, especially not in Germany. Textbook

[6] Cf. https://www.finanzen.at/nachrichten/aktien/squirrel-ai-learning-appears-at-2019-slush-helsinki-as-the-only-invited-chinese-education-company-with-derek-haoyang-li-sharing-the-concept-of-ai-powered-education-1028785267

publishers (such as Duden Lernattack, etc.) and other providers in the after-school market (e.g. SofaTutor) could enter this market in the foreseeable future.

It is interesting that many identified providers are also aiming to place their offerings in school classrooms (Bettermarks – see below – is one example).

MICRO LEVEL EXAMPLE II: Bettermarks – AI-powered learning for mathematics

Personalized learning for tutoring – and increasingly for regular classes – in mathematics, grades 4 to 11, 100% curriculum coverage, content for all competency areas, assignments for every learning objective and achievement level, automated assessment

Description
Bettermarks is like a math book with an integrated tutor. Students see right away whether they have solved an assignment correctly or incorrectly. However, they also get tips, help, explanations and, if necessary, a path to the solution using the numbers from the assignment. This has the advantage that students can experience a eureka effect as they work through practice problems.
The problems themselves contain adaptive learning aids, solution examples with explanations, various input and visualization tools and intelligent error diagnostics that give feedback tailored to the mistakes made when solving the problem. The system recognizes equivalent solutions, accepts alternative solution paths and thus gives students considerable freedom.
For teachers, Bettermarks acts like a virtual assistant: It automatically grades all assignments and displays the class's academic achievement level.

Relevance
Bettermarks is the most successful mathematics tutoring service in Germany that uses adaptive learning. The history of this now-established startup perfectly illustrates the specific situation in Germany. The company is increasingly trying to make its application a standard offering for regular classroom instruction as well, largely in response to the pandemic.

Similar examples found by the search
Somewhat comparable German providers that target mathematics and the after-school market (but still lack AI components): SofaTutor, Serlo, Scoyo, various video channels.
There are several established international offerings that use AI, e.g. ALEKS (No. 34).

Sources
Bettermarks: no. 15 in the search list
Company website:
https://de.bettermarks.com/
Software and company media coverage:
https://www.deutsche-startups.de/2018/10/18/bettermarks-zahlencheck-2016/
https://www.youtube.com/watch?v=jemGGCqzlzc

Key aspects in the evolution of Bettermarks:

First, this is a growing edtech start-up, which are still rather rare in Germany. Its history also shows that these solutions have to travel a long, arduous road before becoming an everyday part of school instruction.

Second, Bettermarks seems well on its way to moving from tutoring to individual support in regular classroom instruction. In addition to an increasing number of school licenses, it has also sold a state license to the Berlin Department for Education, Youth and Family, no doubt in response to the COVID-19 crisis.

Third, Bettermarks may also represent the prospect of increasing AI integration in applications initially based on error analysis algorithms and not AI. As user numbers grow and the pool of (anonymized) user data thus grows, Bettermarks will have greater opportunities to build models and thus integrate AI components.

Finally, it is worth noting, from a pedagogical perspective, that an AI-supported "new classroom" application is being used for mathematics classes at the School of One in New York. Lesson plans for upcoming classes, each personalized and tailored to the student's academic achievement level, are combined with methodological variants that are designed to make the content more accessible to students.[7]

iFLYTEK from China combines the micro and meso levels. According to the company, its application/platform, which was developed primarily for language learning, can be used to craft specific performance-based learning paths for each student based on an AI analysis and extensive data collected from learning processes.
Its AI components are thus expected to help personalize learning while optimizing lesson preparation.

MICRO/MESO LEVEL EXAMPLE: English listening and speaking teaching platform from iFLYTEK: classroom management

Supporting teachers and students in learning English (listening and speaking exercises, materials selection, test creation and analysis).

Description
This English listening and speaking teaching test platform from China is a comprehensive district-level teaching and testing solution covering English listening, speaking, teaching, learning, testing and assessment based on iFLYTEK's intelligent speech recognition and AI applications. The platform provides many teaching and testing resources and supports the preparation and administration of common district-level exams, school-level exams and daily class quizzes. It helps teachers plan and conduct English lessons and helps students with personalized self-study. The system provides automated test and lesson recording and assessment.

Relevance
iFLYTEK is one of the largest, most highly regarded AI and language technology companies in China and has developed a series of AI-based products to support teaching, learning, management and assessment:

- English speaking and listening assessment applications are used in China's two most important exams: the high school entrance exam and the college entrance exam.
- The iFLYTEK Smart Campus solution has been validated at nearly a thousand schools in many towns and can handle applications such as subject selection, lesson planning and roll taking.
- iFLYTEK's VR classroom is a multi-school, multi-terminal AVR solution consisting of VR smart hardware, VR content and the FLY VR Cloud Classroom SaaS platform for primary, secondary and tertiary education, vocational and safety training as well as other fields.

Similar examples found by the search
Baidu (no. 57), Tecent (no. 98), Sensetime (no. 99), Liulishuo (no. 53)

Sources
iFLYTEK: no. 94 in the search list
https://www.iflytek.com/edu, Min Zhang (Chinese guest researcher at HU Berlin)

[7] Cf. https://www.bertelsmann-stiftung.de/de/mediathek/medien/mid/passend-fuer-jeden-wie-massgeschneidertes-lernen-moeglich-ist

MESO LEVEL EXAMPLE: Knowledge Analysis Technology (KAT) from Pearson Education – essay scoring

Reducing teacher workload related to grading text-based assignments
It may also help students write essays in the future

Description

The internet-based "KAT" application combines two functional domains: LSA = automatic speech recognition and computational linguistics, and IEA = text analysis for grading written work for various traits of writing: ideas, organization, conventions, sentence fluency, word choice, etc.
Other notable features found in Pearson's Knowledge Analysis Technologies engine:
RMM (reading maturity metric) – automatic assessment of the essay's reading level and Versant technology that can analyze language to distinguish between native and non-native speakers.

Relevance

- Reduction of teacher workload by assisting with grading
- Support for students writing essays by providing formal and content cues
- Critical issue: the teacher must have the final say on grade/assessment
- Pearson Education is the world's largest publisher of textbooks and is pursuing this application very vigorously. The software's functionality will likely progressively improve over time.

Similar examples found by the search

ETS E-Rater Scoring Engine (no. 96), Project Essay Grade (no. 97)

Sources

KAT: no. 95 in the search list
Link to the offering: https://windows10updater.com/3-automated-essay-grading-software-every-teacher-needs-use
Pearson Test of English Academic: Automated Scoring (2015)
https://pearsonpte.com/wp-content/uploads/2015/05/7.-PTEA_Automated_Scoring.pdf
http://assets.pearsonglobalschools.com/asset_mgr/legacy/200727/IEA_FAQ_261_1.pdf
https://images.pearsonassessments.com/images/assets/kt/download/IEA-FactSheet-20100401.pdf

As a major international textbook publisher, Pearson was an early adopter of digital support for examinations and certifications. It was thus a logical step to start developing and offering AI-supported applications for grading students' solutions in quizzes and assessments. While the algorithmic evaluation of a student's academic achievement level is fairly straightforward (based on "correct" and "incorrect" answers), AI can unlock considerable advances in other areas, too, especially with unstructured or poorly structured data such as essays.

There are two main reasons why this AI application is attractive as a product and a representative of its class: First, it promises to handle grading for teachers – an often unloved and time-consuming part of their jobs. Second, AI-based automated assessments are also essential for adaptive learning, i.e. formative learning assistance intended to individually support students.

A current Weizenbaum Institute project on artificial intelligence in language learning ties together the two meso-level examples by showing that corrections made by specialist teachers and AI engines are now identical around 70% of the time – roughly the same percentage as when the corrections are made by different human teachers.[8] This shows that AI-based assessment holds tremendous market and development potential.

MACRO LEVEL EXAMPLE: Watson Education Classroom (IBM) – multi-functional cognitive system for schools

Supporting lesson planning and management of the organization (school, school operators, etc.) and enabling personalized adaptive learning	
Description Watson Education Classroom is a cloud service solution from the US that helps teachers deliver adaptive teaching to improve student outcomes. Teachers can search for and share learning content, including lesson plans, tests and worksheets, all with an intuitive, teacher-focused interface. Watson Education Classroom components: ▪ *IBM Watson Element for Educators:* Collection and aggregation of multiple academic, social and behavioral data sources. By making performance tracking paperless, educators have more time for face-to-face conversations with students. They also get instant feedback to make instructional decisions. ▪ *IBM Watson Enlight for Educators*: Browser-based planning tool for supporting teachers with curated learning content and access to the analyzed academic strengths and weaknesses of students. Data sources: Apple iPads in classrooms and recording systems throughout the school district.	**Relevance** Cognitive systems, when appropriately set up and trained, can generally support teaching and learning processes in many areas. One pedagogical vision for the future could be “our school’s knowledge network”. However, the effort required for implementation still seems significant: IBM announced many things for its “Education Industry” Watson market segment between 2016 and 2018 but has reported almost no results since. **Similar examples found by the search** Trending: Google Classroom (no. 32 in the search list). **Sources** Watson Education Classroom: no. 18 in the search list Link to the offering: https://www.ibm.com/watson/advantage-reports/ai-social-good-education.html Reports on projects: https://www.ibm.com/blogs/think/2020/01/on-the-baroque-art-trail- with-ibm-watson/ https://www.academia.edu/43743006/IBM_Watson_Industry_Cognitive_Education_Methods https://www.sciencedirect.com/science/article/abs/pii/S0747563218301092

This example represents solutions that claim to take a comprehensive approach that addresses all three levels. However, no such holistic application has yet been implemented for primary and secondary education.

We identified partially AI-based solutions for macro-level tasks such as Kidaptive (adaptive learning platform with performance predictions), Ofsted (prioritization of school inspections based on school performance analyses) and iFlytek (see above, which also offers performance analysis and district-level exam preparation and administration).

Nonetheless, cognitive systems such as IBM Watson are particularly suited for AI application development since they integrate more applications at all three levels.

[8] Cf. https://www.weizenbaum-institut.de/en/news/sprachen-lernen-mit-kuenstlicher-intelligenz/

It can be assumed – and deduced from various announcements – that major international providers, especially those in China and the US, will be innovating in this direction. These trails will not be blazed by the education sector, especially not by primary and secondary schools. Instead, growing fields such as business intelligence will produce solutions that are modified and applied to the educational sector, especially for macro-level use.

In the German market, AI-based applications that can handle forecasting and management for schools and school operators will most likely arise from more extensive and intensive data use in established LMSs (e.g. itslearning) or emerging school clouds (e.g. HPI Schul-Cloud).

One initiative is particularly interesting in this context: “DATAFIED”, a joint project funded by the German Federal Ministry of Education and Research. It consists of four projects that analyze datafication, i.e. the data collected at all levels of the school system, and the effects of datafication: school supervision and schools, school information systems and school management, learning software and teaching, and teachers and students in the classroom. It aims to formulate “actionable implications for future decisions regarding the layout of datafication in the education system”, specifically for “schools as an institution”.[9]

[9] Cf. https://datafied.de/datafizierung-und-schule/

4 Opportunities, challenges and risks

What technology trends loom on the horizon, what application areas will be targeted by highly promising innovations, and where do the problems and challenges lie? To answer these questions, we analyzed relevant scientific studies. However, since many of them were still in the research or early development stage, we also asked experts[10] online, focusing mainly on their assessment of possible applications and challenges. The answers to these questions are presented below in several short sections, each supplemented by the online survey results[11].

1. **Insufficient number of solid empirical studies on "better" learning with AI**
   Only a few AI-based learning technologies have been thoroughly researched and correlated with better learning outcomes (e.g. Kulik & Fletcher 2016 on the ANDES system, also reports out of China on Squirrel AI). However, almost all of the studies focus on the cognitive dimension of knowledge acquisition. Many other systems have been the subject of research publications involving promising pilot tests with prototypes, but none are large-scale studies. Data mining / machine learning-based processes in particular still have not proven their effectiveness in large field studies.

2. **Very few studies have evaluated AI systems from a learning theory perspective.**
   There have been only a few attempts to analyze and assess AI from a learning theory perspective. Tuomi (2018b) made an attempt to compare the learning abilities of convolutional neural networks to Vyogtsky's cognitive development theory. The study found that AI tends to support post-behavioral scientific models and thus exhibits cognitive limitations. At the same time, the Vygotskian model of cognitive development suggests new architectural principles for developing AI that supports human learning. Tuomi (2018b) thus asks, "What would machines need in order to learn and what could they learn from learning research?"

3. **There are not enough studies investigating the transferability of AI-supported educational technology between different education systems.**
   Research shows that some edtech processes (e.g. cognitive processes of knowledge acquisition) can be readily transferred to a large number of learners and thus educational technologies building on these processes have the potential to scale globally. The success and acceptance of other approaches, in contrast, depends heavily on the sociocultural properties and characteristics of the educational system itself (e.g. relevance of privacy, role of teachers, fundamental didactic principles). Not enough research has been done into the factors that determine transferability.

   Three-quarters (74%) of the 49 experts surveyed generally favor the use of AI in schools. In the workshop, however, they noted that the aforementioned lack of research regarding evidence of the positive effects of AI on learning would discourage schools from adopting AI more enthusiastically. The experts all agreed that applied research was urgently needed before rolling out AI on a large scale.

[10] We asked 40 experts working in academia, research and consulting (55%) or in public institutions, governmental organizations or civil society (20%) in December 2020 and January 2021. 63% of the respondents reported having considerable or very considerable expertise in AI.
[11] The annex presents the methods and tools used in the trend study as well as charts illustrating selected core findings.

4. **As AI is used more and more in education, large summative assessments will be replaced or supplanted by smaller formative assessments.**
   Many research projects attempt to study the use of AI for automatic test generation and grading. Much of this work focuses on automating the summative assessment in a bid to reduce teacher workload. One possible unintended consequence is the increasing replacement of highly demanding tests with frequent, less demanding formative assessments due to the diminishing marginal costs and effort of each assessment. Current AI systems are very capable of pooling evidence from various complex data sources and utilizing them for real-time pattern detection. Cumulative formative assessments could therefore largely eliminate the need for highly demanding examinations.

   The vast majority (78%) of survey respondents believed that it would be a good idea for AI systems to reduce teacher workloads so that teachers could devote more time and energy to personally supporting student learning processes. Workshop participants also identified supporting teachers and reducing their workloads as core objectives. However, respondents were largely skeptical about AI's ability to automatically generate and grade tests: 78 percent viewed automated assessments as technically feasible, but only 57 percent described them as desirable.

   In contrast, respondents' assessments of the desirability and technical feasibility of AI applications used for administrative tasks (e.g. lesson planning) and individual student support fell within a very narrow range, with both categories reaching 95 percent.

   Respondents were skeptical about the prospect of obtaining reliable AI-based performance and achievement forecasts and of using robots as virtual tutors. The desirability scores for both scenarios were much lower.

5. **In addition to cognitive applications, AI will also be used in the future to diagnose metacognitive abilities.**
   AI-based applications are increasingly being used to diagnose student attentiveness and conversational dynamics during computer-aided learning. The ability to learn and work collaboratively and be a good team member can also be diagnosed through data analytics (cf. Luckin et al. 2016).

6. **Emotions are increasingly playing a role in AI-based learning processes.**
   Emotion also plays a growing role in educational technology, facilitated and technologically driven by progress made in AI-based analyses of gestures, facial expressions, speech and sensor data. This trend may lead to the development of "learning companions" (Yadegaridehkordi et al. 2019) but requires a careful assessment of how the data is used.

   For the respondents, using AI to analyze video recordings of classes and then automatically generate educational recommendations for teachers – a rather common scenario in China – was neither technically (reasonably) feasible nor particularly likely or desirable. However, they were in favor of AI-based applications that helped teachers manage collaborative learning and assess academic achievement. When it comes to supporting student learning, respondents believe AI holds out the most potential in personalized, self-directed learning and independent exercises.

7. **AI opens up entirely new vistas in subjects such as foreign languages.**
   While researchers have been experimenting with AI-based educational technologies in subjects such as science or mathematics for some time and have found empirical evidence of AI's effectiveness, we have increasingly observed the impact of AI processes in language classes – including advanced speech and text analyses, high-quality automatic translations or essay scoring systems. However, it will take didactically astute methods to exploit the full potential of these processes and thus improve language classes by what may be a significant amount (however, also see no. 8).

8. **AI and its ability to assist learners with cognitive deficiencies such as dyslexia, legasthenia or dyscalculia.**
   AI processes harbor tremendous potential for developing analyses, forecasts and support for students with learning disabilities such as dyslexia, legasthenia or dyscalculia. However, some researchers have challenged the idea of using technology to compensate for disabilities and thereby making students more dependent instead of teaching them coping strategies (Drigas/Ioannidou, 2012).

9. **AI: a supportive technology for students with sensory or physical deficits.**
   As digital systems mediate more and more educational processes, it becomes increasingly important to employ educational technologies inclusively and thus avoid raising any barriers to their use. AI can be used for more than "just" supporting students with cognitive deficits. Its assistive function (e.g. reading aloud, BCI functions[12]) also makes it essential for students with sensory or physical deficits. Educational technologies have to be compatible with these (often personal) assistant systems.

   The survey responses confirmed what the academic literature said: Almost all the experts surveyed described using AI to support students with disabilities as highly desirable. However, they assigned lower ratings to this scenario's technical feasibility and particularly the likelihood of it occurring in the next five to ten years. Also, ethical issues urgently require greater consideration.

10. **Hybrid human-AI use preferred over purely adaptive applications.**
    Adaptive systems are being designed and used for a growing number of applications in education. However, their impact is pedagogically disputed and, in some cases, carries the risk of limiting people's autonomy and freedom. More recent research therefore focuses on hybrid human-AI approaches in education, including co-teaching scenarios and greater integration of learning technologies in class. The theoretical and conceptual frameworks underpinning this area of research are still very limited (cf. Holstein et al. 2020).

[12] BCI refers to a brain-computer interface that operates by measuring brain activity (EEG, etc.) without requiring mechanical movements.

11. **Hybrid AI processes will replace pure-play machine learning processes.**
    We have also noticed a broad shift in the AI processes themselves: Whereas "classic" AI-based educational technologies were rule- and knowledge-based (ideally on the basis of psychological theories such as ACT-R[13] as the foundation for tutoring systems), we have observed a recent focus on statistical machine learning processes (the rise of educational data mining). Since machine learning processes excel at pattern recognition but are hard to explain, it has become increasingly popular to use hybrid cognitive AI processes that combine data-driven insights with knowledge-based explanations (cf. Wahlster 2020).

12. **AI has enormous untapped potential in school consulting and lesson development.**
    It is striking that most school-based AI projects have focused on conducting experiments or applying AI at the learning/teaching level. AI is employed at the macro level in many public and private domains (to intelligently plan production at manufacturing companies, for example), but schools rarely figure among them. Learning analytics approaches are far more widespread at universities than at primary and secondary schools. AI also holds still-underutilized potential for teachers (e.g. by making recommendations during digital lesson planning) (cf. Strickroth 2016).

In addition to these findings on potential applications, researchers – along with our survey and the experts in the workshop – have highlighted the following risks and challenges:

13. **Data protection and data security.**
    All AI applications are based on the large volumes of data generated in schools at every level: at the micro level of learning with intelligent learning software, at the meso level of classes and lessons (in learning platforms, education clouds, etc.) and at the macro level of school management. All these segments face the same questions: What data is being collected? How is it being algorithmically processed, analyzed, evaluated, transferred and interpreted? The fierce public debate on the data ethics of AI development (including concepts such as "explainable AI", AI as a "black box" and "biased algorithms") covers ethical as well as legal, technological and political aspects that are not yet settled or still disputed.[14]

    The experts clearly viewed these aspects as extremely important and consistently prioritized them when considering possible risks. After all, after healthcare, primary and secondary education are among the most sensitive areas in which to use "intelligent" systems. Algorithmically generated recommendations or forecasts could have serious or even extensive personal consequences – for good or ill. This is especially true since the greatest need for assistance often comes with the greatest risks; prime examples include automated assessment and grading systems for tests or competency analyses and the associated risk of biased data or algorithms.

    Conventional data security considerations loom large in primary and secondary education as well. What can be done to prevent data collected in one system from being included in other – tightly connected – applications? What data anonymization and pseudonymization standards are

[13] ACT-R, which stands for Adaptive Control of Thought-Rational, is a cognitive architecture, i.e. a computer-based model of cognitive processes.
[14] Cf. sources such as https://datafied.de/datafizierung-und-schule/.

absolutely necessary with regard to the development and use of AI applications in schools? How can these security settings be implemented in a technologically reliable fashion?

14. Discrimination against minorities

Continuing with the data bias problem, it should be specifically noted that research (Blanchard, 2012) shows that data-driven AI processes pose particular risks when applied to minorities. Since the available data resources determine the quality of the support functions obtained through data analyses, there is a risk that datasets do not adequately represent a particular population, such as students with disabilities. These students are treated as outliers in AI algorithms and thus will probably not benefit much or at all from the adaptive or assistive functions.

For this reason, the surveyed experts believe it will be tremendously important for teachers and school administrators to develop appropriate skills and competencies in the future. Data and AI literacy are essential in order to weigh the – potentially unavoidable long-term – risks of AI-based systems in an area as fraught as primary and secondary education and use available tools appropriately. It should be noted in this context that most teachers and parents have rather critical attitudes toward AI. That is why academic observers believe there is a significant need for ethical reference systems for AI use and research, particularly in education (cf. Drigas/Ioannidou 2012, Tuomi 2018a, among others).

15. AI promotes outdated teaching methods

Finally, the experts see a risk that AI could promote teaching methods whose foundations are pedagogically unsound. For example, it is not necessary helpful to use written communication to transfer knowledge to children who have been using speech perfectly from a very young age (see Riener & Willingham, 2010). AI systems that use text-based communication, in other words, might employ less effective learning methods for practicing complex skills. Many common AI-based learning, training and testing apps also rely on time-worn teaching methods (e.g. teaching to the test).

Despite these concerns, the respondents in this study consistently see potential in AI learning technologies – particularly for children with disabilities. When asked to classify educational AI scenarios as more of a risk or more of an opportunity, the experts largely situate the opportunities in individualized learning supported by learning analytics and recommendations and in smart, adaptive self-study mobile and desktop apps. Automated suitability and achievement forecasts and automated grading, in contrast, polarize opinion and provoke far more skepticism as long as a teacher is not guaranteed to have the final say. However, the experts only rarely label an AI technology per se as clearly risky or promising; it depends on the concrete application and particularly the concrete goal. For example, essay scoring can effectively and safely reduce teacher workloads but is ethically questionable when used to evaluate college application essays.

5 AI between probability and desirability

The described survey findings were then discussed at a workshop[15] revolving around the key question of what AI-based educational technologies the experts believe would not only be desirable but also highly likely to be implementable. If these statements are mapped on a matrix consisting of a “probability” axis on one hand and a “desirability” axis on the other, it produces the following diagram:

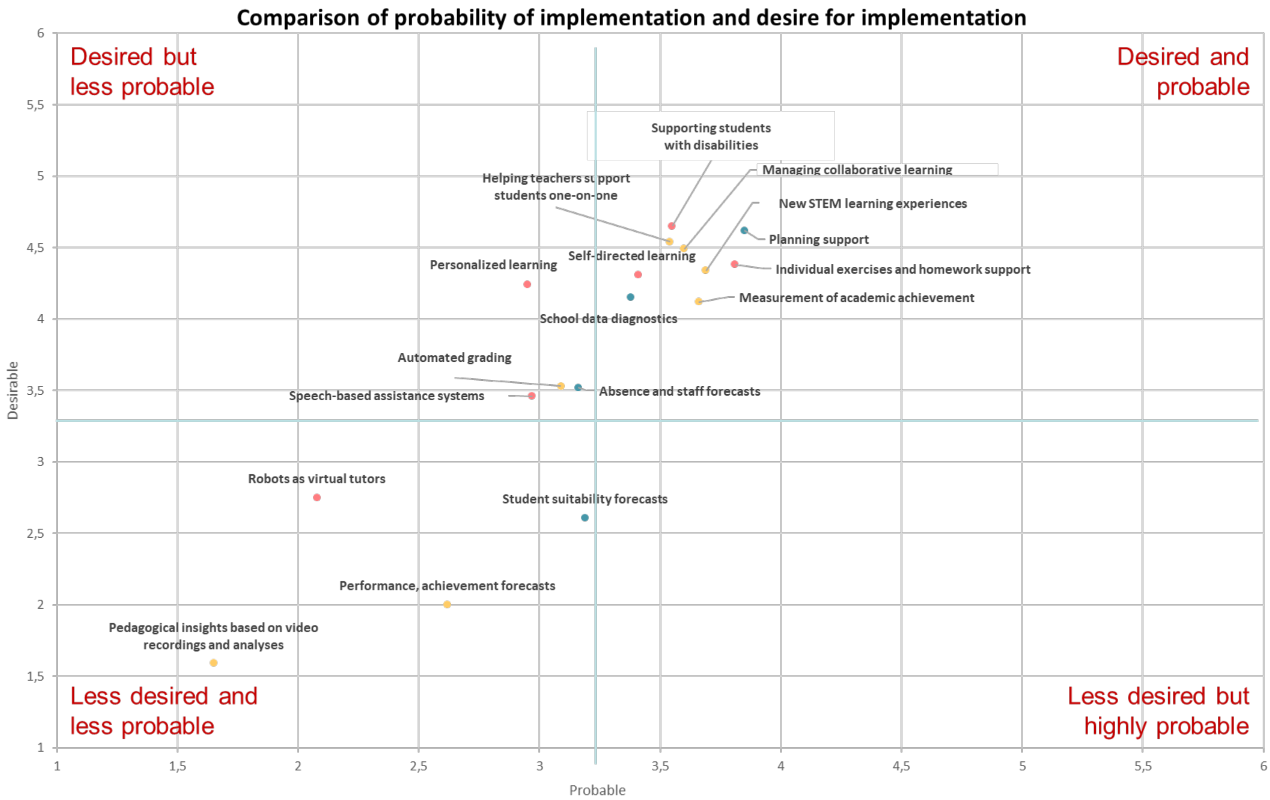

Figure 8: Matrix of AI@School scenarios between probability and desirability (color legend for dots: blue – macro level, yellow – meso level, red – micro level)

Most of the application scenarios presented here are virtually guaranteed to succeed, being classified as both desirable and probable (upper right-hand quadrant). This section contains scenarios in all three application areas: school organization, teaching, learning. Most of the experts surveyed applaud the use of AI-based educational technology for managing, planning and diagnosing various school processes and tasks. Also, they find the use of AI-based solutions to support disadvantaged students and generally enable teachers to devote more one-on-one time to students to be both desirable and probable.

It is striking that the experts believe that none of the available scenarios are probable but explicitly unwanted (bottom right-hand quadrant). Any AI use cases in school that had fallen within this quadrant could have occurred despite being completely undesirable from the experts’ point of view.

[15] In February 2021, 20 experts in primary and secondary education and/or AI-based teaching/learning technologies participated in a two-and-a-half hour workshop on “AI@School between vision and reality”. The annex contains the basic schedule and a list of participants approved by Deutsche Telekom Stiftung.

It is interesting to consider the four scenarios that are deemed desirable but not probable (upper left-hand quadrant). This quadrant contains some of the core promises of AI, such as personalized learning, speech-based assistance systems and automated grading – in short, some of the use cases that tend to be positively highlighted in the current debate.

Finally, it is also noteworthy that the respondents appear to be broadly skeptical about AI-based achievement or performance forecasts, both in terms of their desirability and their probability (bottom left-hand quadrant).

One way to interpret the desirability/feasibility matrix is that the experts tend to be hesitant, if not dismissive, about the more ambitious AI scenarios in school settings. The group applauds some of the core AI visions for primary and secondary education in principle – including individualized learning and virtual assistants – but harbors doubts about their reliable technical feasibility. Other visionary AI schemes, particularly those involving automatic classifications and forecasts (i.e. predictive analytics), are viewed by the experts as neither technologically feasible nor pedagogically desirable. Their rather dismissive attitude toward visionary AI scenarios may be attributed partly to a lack of scientific evidence and user experience and partly to the desire not to undermine or devalue the future role of teachers; this debate has yet to be conducted.

6 Conclusions

Four key recommendations should be made based on this study:

1. Educational innovation process with room for experimentation.

In many respects, AI-based educational technologies and the expectations invested in them still have to pass field testing in the German school systems with all its idiosyncrasies and requirements. They often suffer from a lack of scientific evidence as well as practical testing and experience, especially when it comes to core pedagogical issues such as performance diagnostics and assessment, learning guidance and forecasting. That is only compounded by the described risks and shortcomings of purely data-based AI processes for learning applications.

For that reason, this study's first recommendation is to drive didactically oriented innovation processes and create new space and opportunities to experiment with smart applications.

In other words, given the fierce competition with Chinese and US learning technology providers, Germany should not only invest more in research and (product) development but also enable and systematically evaluate the field-testing and "grounding" of these technologies in the regular school day. This could be done by establishing special "AI innovation schools", for example. Some progress has been made on that front: The Institute for Quality Development at Schools in Schleswig-Holstein (IQSH) in Kiel is working to develop an AI-based app to support literacy development in elementary schools.[16] The University School Dresden is exploring ways to support personalized learning with AI (i.e. adaptive learning) in connection with a comprehensive digitalization strategy in project-based teaching/learning settings.[17]

The purpose of these "AI innovation schools" is to test existing and obviously "functioning" solutions for rule-based learning (STEM subjects and language acquisition) as well as applications that are mostly still in the development and early product development phase, particularly for metacognitive skill development and concept-based learning formats.

2. Establish co-teaching and assisted learning as core strategies.

One key argument for using AI-based applications in schools is their largely "assistive" function – whether in providing more one-on-one assistance to children or in performing organizational and advisory tasks – in both the classroom and the school as a larger organization.

AI technologies are predictably embraced and accepted wherever they can effectively, reliably and cost-effectively help teachers handle their expanding workloads without violating data privacy laws or running afoul of other legal obligations. This trend will probably only accelerate amid the growing teacher shortage.

[16] Cf. https://www.schleswig-holstein.de/DE/Landesregierung/IQSH/Service/Newsletter/documents/2020/202010Newsletter.pdf;jsessionid=C8721DEEF502215D7FBCE1FF6076E8C7.delivery1-replication?__blob=publicationFile&v=2
[17] Cf. https://tu-dresden.de/gsw/forschung/projekte/unischule/konzeption

Education scholars also broadly agree that AI systems should support and supplement teachers in face-to-face learning settings, not replace them (co-teaching in hybrid learning arrangements, flipped classrooms, etc.). In other words, the future role that teachers will play as they employ digital technologies more and more will have to be re-defined to some extent. Like other professions, teachers might benefit from AI technologies that perform certain tasks for them, such as purely cognitive knowledge transfer, exercises and repetition, testing, evaluation, administration, et cetera. That would free up time and energy for teachers to spend on higher-value education/coaching tasks, particularly those aimed at providing one-on-one assistance to students and helping them realize their potential. It is important to focus less on AI technology visions and more on concrete needs and problems: The main goal of AI in primary and secondary education should always be to support, assist and free up teachers so that they can devote more social and emotional energy to their students, whether remotely or in person. That goal may be particularly easier to achieve with "intelligent", mobile and user-centric learning applications, particularly if they are easy for students and teachers to use and understand, than some complex IT systems built in the past.

3. Drive the further development of AI-based applications by providing secure data resources ("data lakes").

If the market and trend analysis in this study is placed alongside the current scholarly debate on the challenges of using AI in the school setting, it suggests that more and more AI components will be integrated in media, tools and platforms used for digitally supported learning and teaching in schools in the years to come. While there will be standalone applications with limited scopes (e.g. for language acquisition or school management), two broader technological focus areas could develop:

a) The smart learning cloud as a highly available infrastructure with counterparts at the state, district or individual school level
b) The "learning companion", an always-available personal learning assistant

The extent to which this foreseeable international trend will unfold in Germany depends on various factors, including the ability to encourage stakeholders – researchers and developers, start-ups, etc. on the supply side, and educational innovators and particularly primary and secondary educators on the demand and user side – to engage with one another in an ongoing cooperative process to develop AI-supported educational software.

Data use and thus data protection will play a critical role throughout this process. One the one hand, self-learning AI procedures are and will remain highly dependent on having access to sufficient data resources for machine learning. On the other, these applications will only be accepted, particularly in schools, if they follow legally and ethically sound and secure rules and procedures. One way to accomplish that is by building and providing "data lakes", i.e. relevant, but anonymized and pseudonymized, test data stocks for developing and empirically testing future AI algorithms for the edtech sector.[18]

[18] The German Federal Ministry of Education and Research's ongoing "DATAFIED" research project focuses on the data-driven measurement of the school system and appears likely to yield results that can underpin the conceptual development of AI applications (cf.: https://datafied.de)

4. Broaden teacher training and establish AI as a training topic

Due to the significance of AI as an upcoming base technology, teachers should be equipped to better understand the pedagogical relevance of these educational innovations along with their capabilities, limitations and potential applications. The goal is to develop teachers' pedagogical competencies even as algorithms increasingly permeate learning and educational processes. This environment will actually demand higher pedagogical standards – not lower ones. Indeed, teachers are already being challenged by the widespread heavy use of "smart" learning applications in the after-school market. Teacher training should thus focus on integrating didactic and educational technology processes and pairing autonomous technology-driven learning phases with social learning processes in the classroom. At the same time, however, curricula and classroom teaching should include AI as a topic in its own right.[19] This can be done in classes such as mathematics or computers and should include teaching statistical skills, among other things.

[19] The KI Campus training platform (currently under development) offers these kinds of classes specifically for teachers and plans to expand this segment in the future.

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8 Annex

8.1 Methodological overview

The trend study whose structure is outlined in Figure 9 employed a systematic search and qualitative content analysis using a category system, a standardized online questionnaire and a focus group. The tools and core findings are presented in Sections 8.2-8.4.

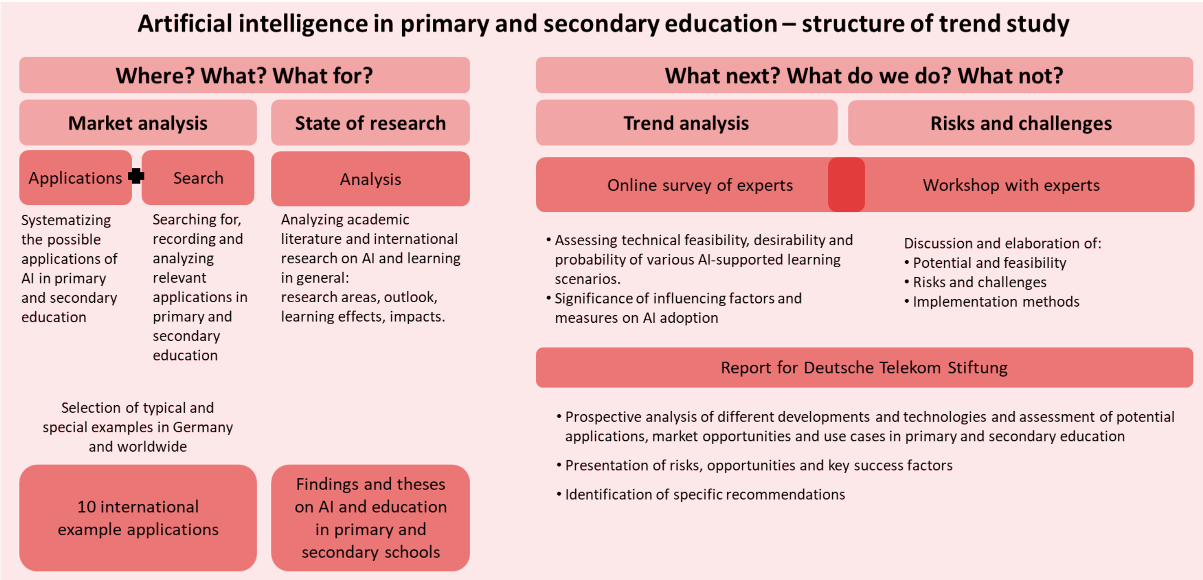

Figure 9: Structure of this trend study

8.2 Search: Category system for recording and analysis

AI-supported applications for school use were identified by conducting a web and literature search and systematically recording the examples found. The recording and subsequent qualitative content analysis was based on the following category system comprising descriptions, providers, activities and other categories:

Company	Application provider
Application	Product name
Core objective/expected benefit	What is the goal?
Brief description	What does the application do? What does it consist of? What objectives does it have?
Application level: macro, meso, micro	What level does the application mainly focus on? Macro - school in its capacity as an organization Target metrics: effectiveness, efficiency in the overall system Meso - school class Target metrics: Learning impact of teaching/learning arrangements or teaching activities Micro - individual or cooperative learning processes Target metrics: learning progress (development of student's potential, acquisition of knowledge/competency)

Macro level: categories	- School evaluation - Performance analysis / standardized test - Performance forecast, drop-out analysis - Room and student scheduling - Economic analysis - Staffing - Other macro level objective:
Meso level: categories	- Classroom management - Learning arrangements, learning process design - Quizzes, tests, assessments - Academic achievement assessment - One-on-one assistance - Conduct, advising, parent relations - Other meso level objective:
Micro level: categories	- Learning: rule-based - Learning: concept-based - Exercises, practicing, homework - Collaborating - Self-directed learning - Self-evaluation - Other micro level objective:
AI component	What are the main AI components being used?
Area of application: subject(s)	Wherever stated
Country of origin	Provider’s domicile
Degree of maturity / market status	1= Established, widely used product 2= Less widely used product 3= Prototype / development stage
Link to product/provider	Where else can you get additional information straight from the provider?
Source of information	What study was the example taken from? (nesta, etc.)

8.3 Online survey on potential and trends

8.3.1 Questionnaire

mmb Institut

Gesellschaft für Medien- und Kompetenzforschung mbH

Expertenbefragung KI und Schule

Willkommen

Sehr geehrte Expertinnen und Experten,

der Einsatz von KI (Künstliche Intelligenz) ist im Berufs- und Alltagleben bereits vielfach Realität. Auch im Bereich Lernen und Schule gibt es inzwischen viele Beispiele für die Anwendung von KI. Unter KI verstehen wir grundsätzlich selbstlernende Algorithmen („intelligente Systeme"), die zutreffende Aussagen, plausible Entscheidungen und verlässliche Prognosen generieren. Nach einer Recherche von mmb sind die meisten KI-basierten Anwendungen im Schulbereich in den USA und China zu finden. In China werden KI-Systeme bereits landesweit genutzt, um Schülerinnen und Schüler (SuS) in ihrem Lernverhalten und Schulalltag zu analysieren. In Japan sind Roboter als Lehrassistenten durchaus gängig.

Und wie sieht der Status quo hierzulande aus?
Um die aktuelle Situation besser einschätzen zu können, möchten wir gerne Ihre Sichtweise und Meinung zu diesem Thema kennenlernen. Dabei geht es einerseits um Ihre Bewertung der didaktischen Potenziale und Herausforderungen, andererseits aber auch um die Frage, welche Rolle KI in der Schulorganisation spielen könnte.

Wir würden uns freuen, wenn Sie sich etwa 10 Minuten Zeit nehmen könnten, um die folgenden Fragen zu dieser Thematik zu bewerten.

Zum Hintergrund: KI in der Schule? Was bedeutet das eigentlich?
Sie möchten etwas mehr zum Hintergrund des Themas "Künstliche Intelligenz und Schule" erfahren? Dann empfehlen wir Ihnen diese Beiträge:

Initiative D 21: DENKIMPULS DIGITALE BILDUNG: Einsatz von Künstlicher Intelligenz im Schulunterricht (2019)

Nesta (GB): Educ-AI-tion Rebooted? Exploring the future of artificial intelligence in schools and colleges

Sie haben noch Fragen?
Bei Rückfragen zögern Sie bitte nicht, sich an uns zu wenden - unsere Kontaktdaten finden Sie weiter unten. Wir stehen Ihnen gerne zur Verfügung. Herzlichen Dank für Ihr Interesse und Ihre Unterstützung!

mmb Institut - Gesellschaft für Medien- und Kompetenzforschung mbH
Folkwangstr. 1
D-45128 Essen

E-Mail: info@mmb-institut.de
Impressum
Datenschutzerklärung

Expertenbefragung KI und Schule

I. KI-Lernszenarien und ihre Realisierung in der Schule

Im Folgenden sehen Sie einige Szenarien, wie KI-Anwendungen im Schulbetrieb für das individuelle Lernen eingesetzt werden können. Bitte schätzen Sie mit Blick auf die kommenden fünf bis zehn Jahre ein: Inwieweit Sie die Szenarien für technisch machbar halten, wie wahrscheinlich es ist, dass sie eintreffen und für wie wünschenswert Sie persönlich das Eintreffen des jeweiligen Szenarios halten.

1. Individuelles Lernen

Personalisiertes Lernen mit auf einzelne Schülerinnen und Schüler zugeschnittenen Lernangeboten (= Adaptive Learning).

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Leichterer Zugang zu Lerninhalten (z. B. mit sprachbasierten Assistenzsystemen wie „Siri“ oder „Alexa“).

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Unterstützung von eigenverantwortlichem und selbstreguliertem Lernen (z. B. durch Empfehlungssysteme).

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Individuelle Übungsphasen und die Bearbeitung von Hausaufgaben.

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Unterstützung des Lernens und Unterrichtens von SuS mit körperlichen oder geistigen Behinderungen durch Kommunikation über Sprache, Mimik oder Gestik.

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Virtuelle Hilfslehrende (Tutorinnen/Tutoren) in Form von humanoiden (menschenähnlichen) Robotern.

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Sehen Sie noch andere - technisch umsetzbare - Szenarien von KI-Anwendungen für Lernprozesse in der Schule? Wenn ja, wie wünschenswert und wahrscheinlich sind diese Szenarien?

Expertenbefragung KI und Schule

I. KI-Lernszenarien und ihre Realisierung in der Schule

Im Folgenden sehen Sie einige Szenarien, wie KI-Anwendungen im Schulbetrieb zum Unterrichten und Lernen in der Klasse eingesetzt werden können. Bitte schätzen Sie mit Blick auf die kommenden fünf bis zehn Jahre ein: Inwieweit Sie die Szenarien für technisch machbar halten, wie wahrscheinlich es ist, dass sie eintreffen und für wie wünschenswert Sie persönlich das Eintreffen des jeweiligen Szenarios halten.

2. Unterrichten und Lernen in der Klasse

Unterstützung der Lehrkräfte bei der individuellen Förderung von Schülerinnen und Schülern.

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Kollaboratives Lernen im Unterricht (Zusammenbringen von Lernenden mit ähnlichen Schwierigkeiten oder mit ergänzenden Kompetenzen).

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Ermöglichung neuer Lernerfahrungen insbesondere in den MINT-Fächern, z.B. durch 3D-Spiele, Realitäts-Simulation oder VR-Brillen.

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Messung von Lernstand und Lernerfolg („formative Evaluation“) inkl. Feedback.

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar							
Eintreten wahrscheinlich							
wünschenswert							

Automatisches Testen und Prüfen (u. a. für Essay Scoring) zur Entlastung der Lehrkräfte bei der Korrekturarbeit.

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar							
Eintreten wahrscheinlich							
wünschenswert							

Videoaufzeichnungen des Verhaltens von Lehrenden sowie SuS und daraus abgeleitete pädagogische Hinweise (z.B. zum Aktivitäts- und Konzentrationslevel einer Klasse/eines Schülers etc.).

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar							
Eintreten wahrscheinlich							
wünschenswert							

Prognosen zum künftigen Schulerfolg und/oder Leistungsniveau von SuS.

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar							
Eintreten wahrscheinlich							
wünschenswert							

Sehen Sie noch andere - technisch umsetzbare - Szenarien von KI-Anwendungen für den Unterricht in der Schule? Wenn ja, wie wünschenswert und wahrscheinlich sind diese Szenarien?

Expertenbefragung KI und Schule

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Im Folgenden sehen Sie einige Szenarien, wie KI-Anwendungen für die Schulorganisation und -administration eingesetzt werden können. Bitte schätzen Sie mit Blick auf die kommenden fünf bis zehn Jahre ein: Inwieweit Sie die Szenarien für technisch machbar halten, wie wahrscheinlich es ist, dass sie eintreffen und für wie wünschenswert Sie persönlich das Eintreffen des jeweiligen Szenarios halten.

3. Schulorganisation und -administration

Verbesserte Schuldaten-Diagnostik und Evaluation (Kennziffern, Leistungsdaten etc.) für das Schul-Management.

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Prognosen zu Fehl- und Ausfallzeiten, Personal, Ressourcen etc.

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Erleichterung der verschiedenen Planungsaufgaben auf der Schulleitungsebene (Raum-, Ressourcen, Stundenplanung etc.).

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Prognosen zur Eignung von SuS für bestimmte Schultypen oder Fächerschwerpunkte (z.B. im Rahmen von Eingangs- oder Eignungstests) (= Learning Analytics).

	1 - sehr	2	3	4	5	6 - überhaupt nicht	weiß nicht
technisch machbar	○	○	○	○	○	○	○
Eintreten wahrscheinlich	○	○	○	○	○	○	○
wünschenswert	○	○	○	○	○	○	○

Sehen Sie noch andere - technisch umsetzbare - Szenarien von KI-Anwendungen für die Schulorganisation? Wenn ja, wie wünschenswert und wahrscheinlich sind diese Szenarien?

Expertenbefragung KI und Schule

II. Generelle Einschätzung zu KI in der Schule

Wenn Sie allein entscheiden dürften, würden Sie die Einführung von KI-Technologien an Schulen eher befürworten oder ablehnen?

1 - voll und ganz befürworten	2	3	4	5	6 - völlig ablehnen	weiß nicht
○	○	○	○	○	○	○

III. KI-Szenarien und ihr sinnvoller Einsatz

Die folgenden Aussagen beziehen sich auf Probleme, die KI-Systeme an Schulen lösen könnten. Wie sinnvoll wäre es nach Ihrer Einschätzung, hierfür KI-Systeme einzuführen?

	1 - sehr sinnvoll	2	3	4	5	6 - überhaupt nicht sinnvoll	weiß nicht
... um die persönliche Beratung von SuS durch Lehrende zu unterstützen.	○	○	○	○	○	○	○
... um leistungsschwache oder -starke SuS besser zu unterstützen.	○	○	○	○	○	○	○
... um die Lernprozesse und Leistungen der SuS genauer zu diagnostizieren und Rückschlüsse daraus zu ziehen.	○	○	○	○	○	○	○
... um Lehrkräfte zu entlasten und ihnen so mehr Möglichkeiten der persönlichen Lernbegleitung zu geben.	○	○	○	○	○	○	○

Weitere, welche:

Expertenbefragung KI und Schule

IV. Einflussfaktoren auf die Einführung von KI

Im Folgenden nennen wir einige Aspekte, die auf die Einführung von KI-Systemen in der Schule einen mehr oder weniger großen Einfluss haben werden. Welchen Einfluss haben nach Ihrer Einschätzung die folgenden Faktoren:

	1 - sehr großer Einfluss	2	3	4	5	6 - überhaupt kein Einfluss	weiß nicht
Datenschutz	○	○	○	○	○	○	○
Digitale Kompetenzen des Lehrpersonals	○	○	○	○	○	○	○
Bedenken des Lehrpersonals	○	○	○	○	○	○	○
Bedenken der Eltern	○	○	○	○	○	○	○
Länderstrategien/Schulstrategien	○	○	○	○	○	○	○
Schuletat/Budget der Kommune, des Landes	○	○	○	○	○	○	○
Digitale Kompetenzen der Schülerinnen und Schüler	○	○	○	○	○	○	○
Vorhandenes Angebot an KI-Lösungen	○	○	○	○	○	○	○
Zeit- und Personalbudget	○	○	○	○	○	○	○
Ressourcen für Wartung und Pflege der Systeme	○	○	○	○	○	○	○

Expertenbefragung KI und Schule

V. Maßnahmen zur Einführung

Wie wichtig und unterstützenswert sind nach Ihrer Ansicht die folgenden Maßnahmen im Zusammenhang mit der Einführung von KI-Technologien an Schulen?

	1 - sehr wichtig / unterstützenswert	2	3	4	5	6 - überhaupt nicht wichtig / unterstützenswert	weiß nicht
Stakeholder (Pädagogen, Entwickler, Pioniere und Startups etc.) in einen kontinuierlichen Prozess der Innovation einbeziehen	○	○	○	○	○	○	○
Umfangreiche Bedarfsanalyse unter Schulverantwortlichen	○	○	○	○	○	○	○
Informationsmaterialien und -veranstaltungen für Eltern	○	○	○	○	○	○	○
Schulungen für das Lehrpersonal	○	○	○	○	○	○	○
Bereitstellung von Personal für Wartung und Pflege der IT-/KI-Anwendungen	○	○	○	○	○	○	○
Bereitstellung eines Sonderbudgets zur Anschaffung von KI-Anwendungen	○	○	○	○	○	○	○
Rahmenregelungen zum Datenschutz	○	○	○	○	○	○	○
Einführung eines Educational Technologists - eine Person, die an der Schnittstelle Technik - Inhalt - Fachdidaktik den (Beratungs-) Prozess an der Schule übernimmt	○	○	○	○	○	○	○

Expertenbefragung KI und Schule

VI. Eigene Funktion

Welcher Akteursgruppe gehören Sie hauptsächlich an?

- ◯ Dienstleister / Produzent von Lernangeboten
- ◯ Anwender / Nutzer von Lernangeboten
- ◯ Wissenschaft / Forschung / Beratung
- ◯ Medien / Freier Journalist
- ◯ Öffentliche Einrichtung / Regierungsorganisation
- ◯ Andere Akteursgruppe, und zwar:

Wie hoch würden Sie ihre eigene KI-Expertise einschätzen?

1 - sehr hoch	2	3	4	5	6 - keine Expertise
◯	◯	◯	◯	◯	◯

Expertenbefragung KI und Schule

Herzlichen Dank für Ihre Unterstützung

Vielen Dank, dass Sie unsere Kurzbefragung zum Thema "KI und Lernen" unterstützt haben.

Wenn Sie keine Änderungen mehr vornehmen möchten, beenden Sie nun die Befragung bitte durch einen Klick auf den Button [Fragebogen absenden].

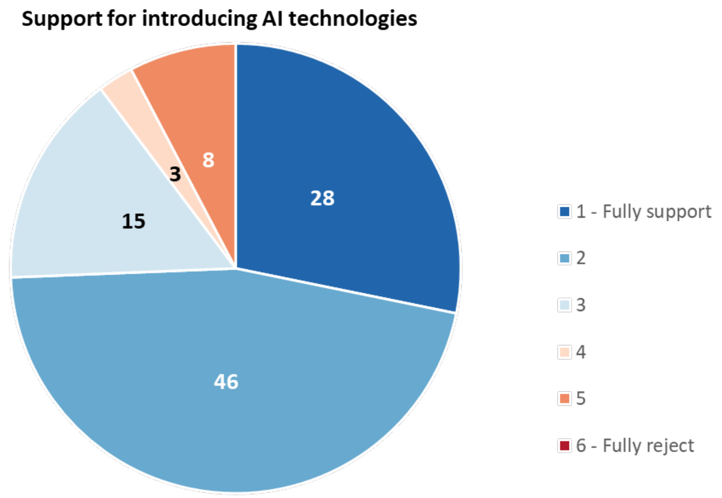
Wenn Sie Interesse an den Ergebnissen dieser Befragung haben, dann geben Sie hier eine E-Mail-Adresse an. Die E-Mail-Adresse wird getrennt von Ihren Antworten gespeichert.

E-Mail-Adresse (optional):

8.3.2 Results of potential and influencing factors in diagrams

We asked 40 experts, over half of whom worked in academia, research and consulting (55%), while 20 percent worked in public institutions, governmental organizations or civil society. 63% of the respondents reported having considerable or very considerable expertise in AI.

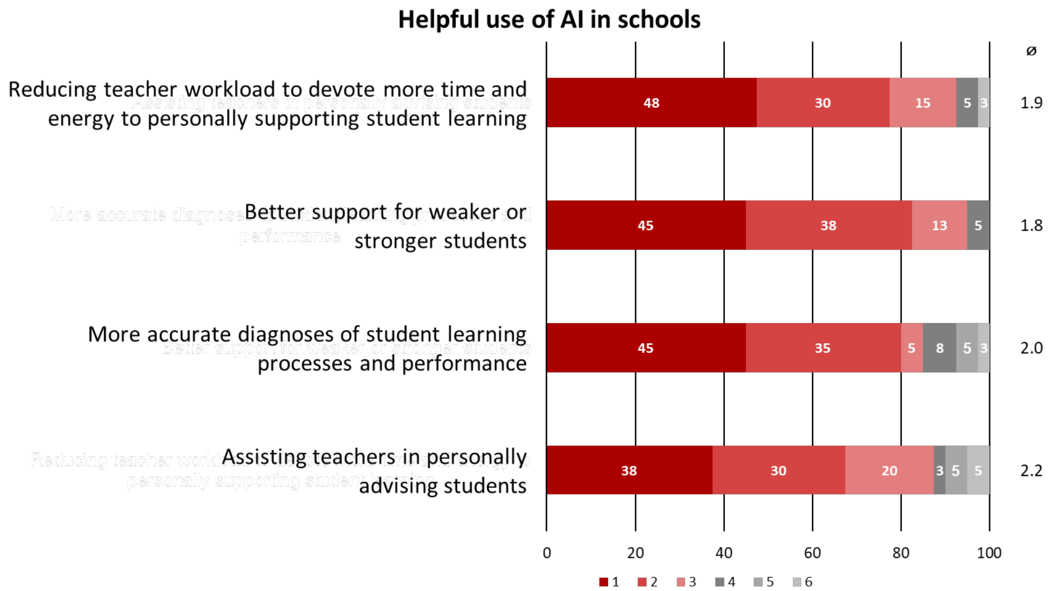
➢ **Three quarters of respondents are in favor of introducing AI technologies in schools:**



Question: If you could make the decision yourself, would you support or reject the introduction of AI technologies in schools?
Scale from "1 – fully support" to "6 – fully reject" | n = 39 | Stated in % | © mmb Institut GmbH, 2021

Figure 10: Result of online survey: Support for AI@School

➢ **Helpful AI use, particularly for reducing teacher workloads and helping stronger and weaker students:**



Question: The following statements refer to problems that AI systems could solve in schools. How helpful do you think would it be to employ AI systems for them?
Scale from "1 – very helpful" to "6 – not helpful at all" | n = 40 | Stated in % | © mmb Institut GmbH, 2021

Figure 11: Result of online survey: Reasonable objectives of AI@School

➤ **Technically feasible, particularly AI-based support for administration and personalized individual learning (micro level applications):**

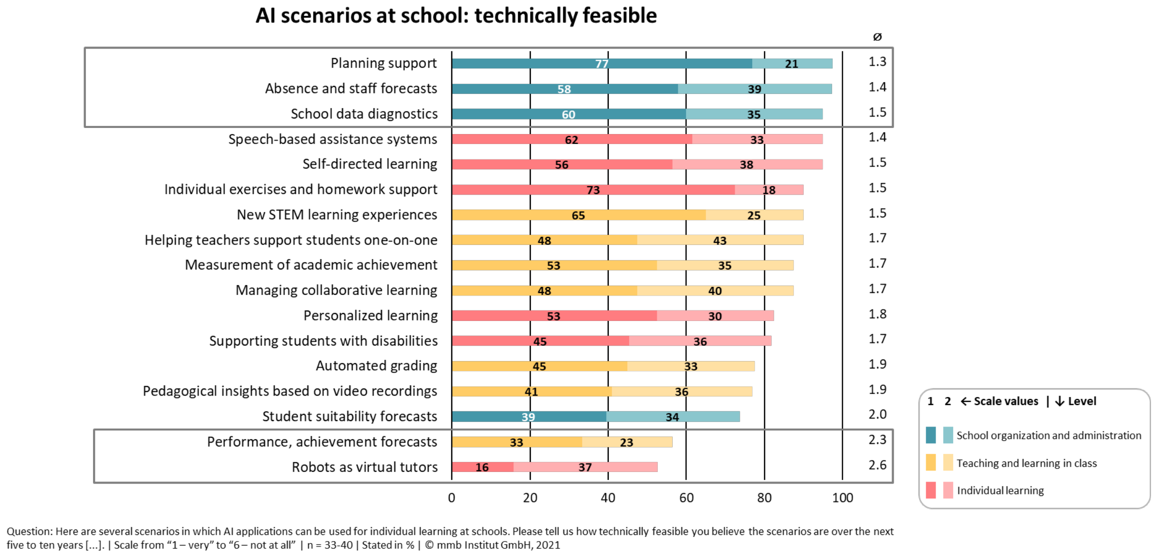


Figure 12: Result of online survey: Technical feasibility of various AI@School scenarios

➤ **Desired AI scenarios for current problems:**

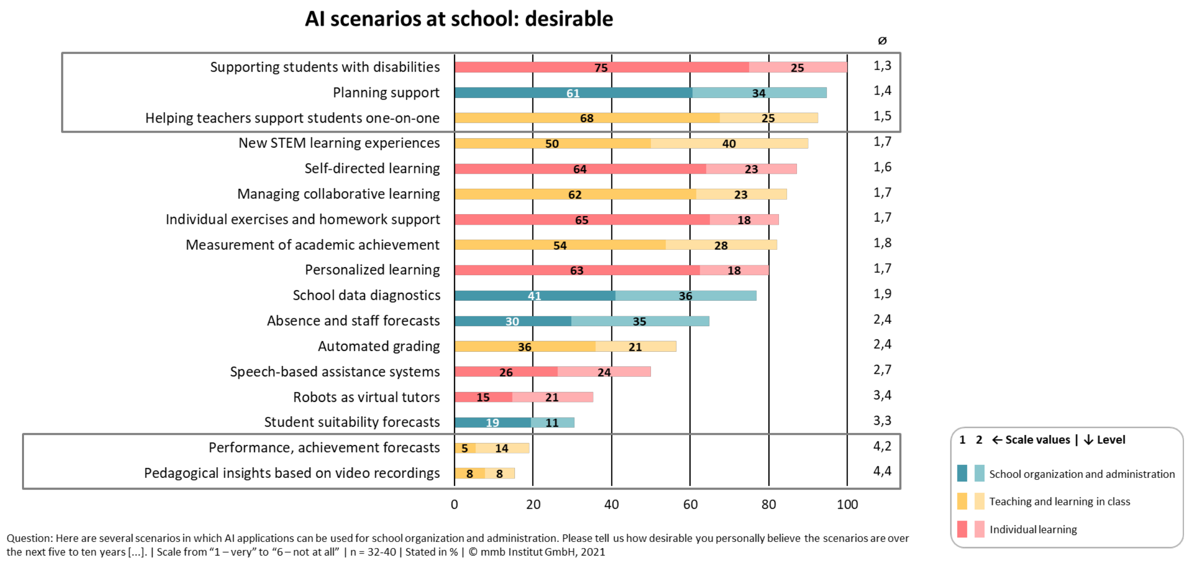
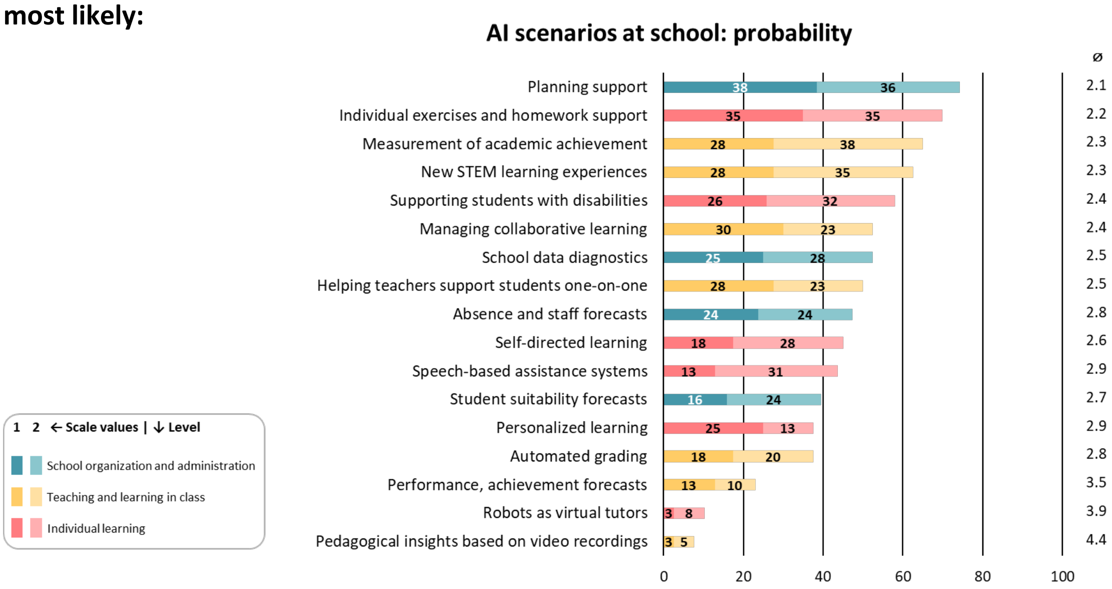


Figure 13: Result of online survey: Desire for various AI@School scenarios

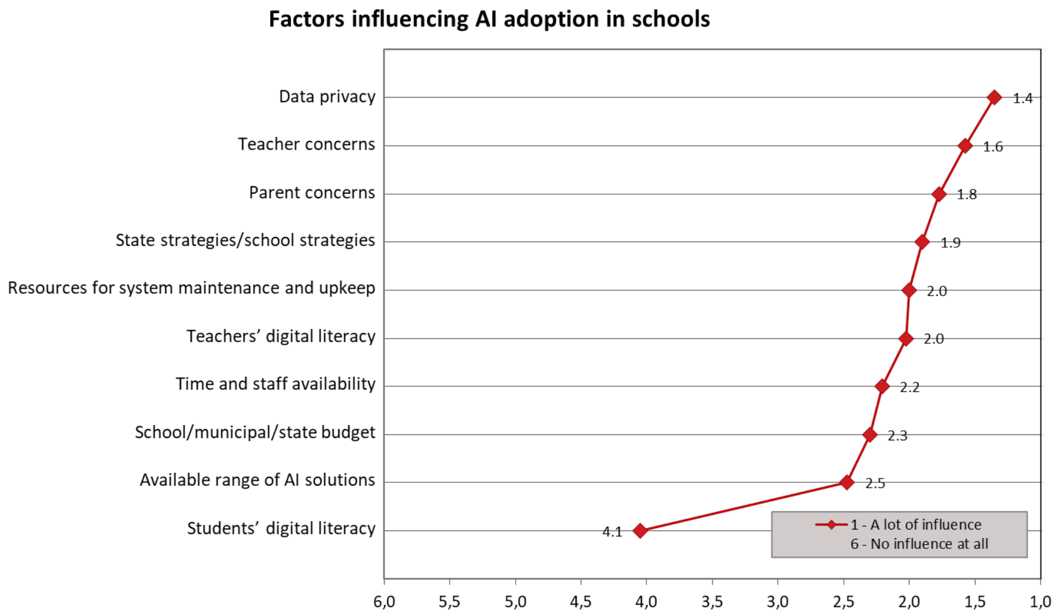
➢ **AI-supported administration, individual exercises and assessment of academic achievement most likely:**



Frage: Im Folgenden sehen Sie einige Szenarien, wie KI-Anwendungen für die Schulorganisation und -administration eingesetzt werden können. Bitte schätzen Sie mit Blick auf die kommenden fünf bis zehn Jahre ein: [...] wie wahrscheinlich es ist, dass sie eintreffen [...]. | Skala von „1 - sehr" bis „6 = überhaupt nicht" | n = 31-40 | Angaben in % | © mmb Institut GmbH, 2021

Figure 14: Result of online survey: Likelihood of various AI@School scenarios

➢ **Data protection and parent/teacher concerns the most important factors influencing the introduction of AI systems in schools:**

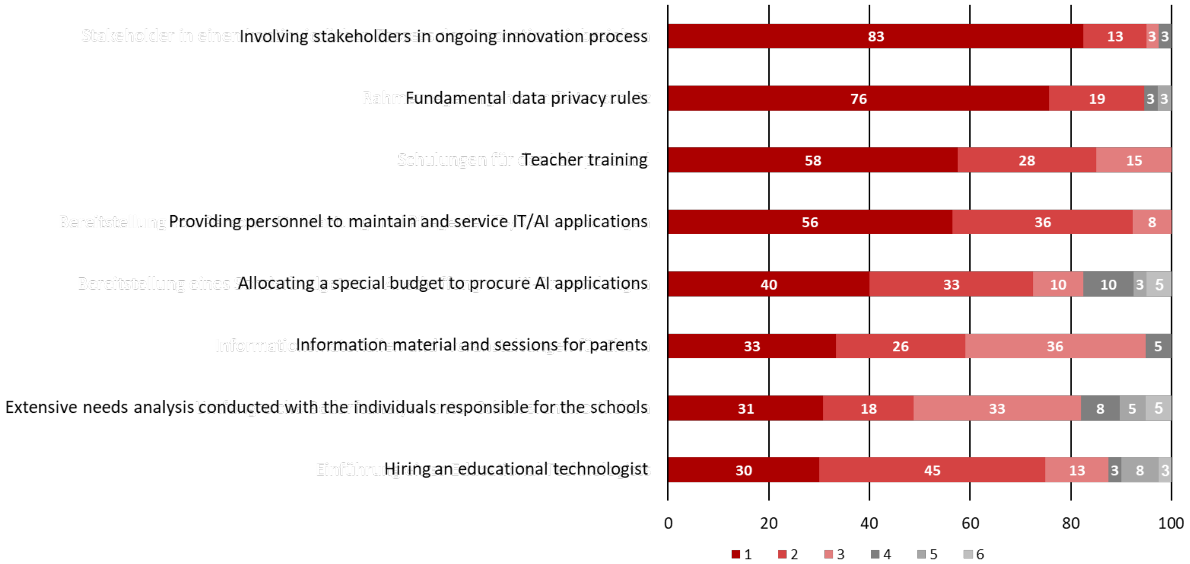


Question: Below, we list several aspects that will influence the adoption of AI systems in schools to a greater or lesser extent. What influence do you think the following factors have? | n = 38-40 | Means | © mmb Institut GmbH, 2021

Figure 15: Result of online survey: Significance of various factors influencing the introduction of AI@School

➢ **In keeping with the significance of the influencing factors: participation and data protection rules play the most important role in introducing AI systems at schools:**

Important measures when introducing AI in schools



Question: How important and worthy of support are the following measures, in your opinion, when introducing AI technologies in schools?
Scale from "1 – very important/worthy of support" to "6 – not important/worthy of support at all | n = 37-40 | Stated in % | © mmb Institut GmbH, 2021

Figure 16: Result of online survey: Most important measures for introducing AI@School

8.4 Expert workshop: "AI@School - Between Vision and Reality"

8.4.1 Schedule

Part A: AI@School – Current status, desires and feasibility

Presentation: AI-based applications in schools

1) Research findings
2) Survey responses for AI@School:
   Technically possible, desired and likely scenarios

Introductions and feedback

Key question: What AI applications have the greatest potential and greatest feasibility in the German school system?

Part B: Discussion of risks and challenges

Survey responses on the most important factors influencing AI adoption

Key question: Where do the possible risks, problems and dangers lie when using AI-based systems in primary and secondary education?

Break

Part C: Joint assessment of central findings and challenges

Opportunities versus risks

Importance versus urgency

8.4.2 Participating experts

Kenza **Ait Si Abbou Lyadini**	Deutsche Telekom IT, Robotics and Artificial Intelligence
Prof. Dr. Maria **Bannert**	TU München, TUM School of Education, Professor for Teaching and Learning with Digital Media
Hans-Christian **Boos**	arago GmbH; Member of the Digital Council of the German government
Noshaba **Cheema**	Max Planck Institute for Informatics, DFKI Agents and Simulated Reality
Prof. Dr. Ulrike **Cress**	Leibniz-Institut für Wissensmedien, Director
Prof. Dr. Hendrik **Drachsler**	DIPF | Leibniz Institute for Research and Information in Education, Educational Technologies unit
Jakob **Flingelli** (representing Axel Menneking)	Deutsche Telekom, Startup Incubation & Venturing, hub:raum; Board Member Support Technology and Innovation
Dr. Gerd **Hanekamp**	Deutsche Telekom Stiftung, Director of Programs
Annika **Klaus**	Deutsche Telekom Stiftung, Communication Manager
Prof. Dr. Tobias **Ley**	Tallinn University, School of Educational Sciences, Professor for Learning Analytics and Educational Innovation
Prof. Dr. Detmar **Meurers**	University of Tübingen, Computer Linguistics
Prof. Dr. Niels **Pinkwart**	DFKI, EdTecLab / HU Berlin, Department of Computer Science
Claudia **Pohlink**	Telekom Innovation Laboratories, Head of Artificial Intelligence @ T-Labs and Member of the Bitkom Board for AI
Dr. Tanja **Reinlein**	North Rhine-Westphalian Ministry of Schools, Section 412: Teaching and Learning in the Digital World, Media Consulting, Educational Materials
Detlef **Reuter**	German Federal Ministry of Education and Research, Section 323: School Infrastructure Support
Thomas **Schmitt**	Deutsche Telekom Stiftung, Project Manager
Prof. Dr. Carsten **Schulte**	University of Paderborn, Head of ProDaBi Project (Project on Data Science and Big Data in School, Deutsche Telekom Stiftung)
Dr. Daniel **Thurm**	University of Duisburg Essen, Mathematics Education
Dr. Ekkehard **Winter**	Deutsche Telekom Stiftung, Executive Director
Prof. Dr. Katharina **Zweig**	TU Kaiserslautern, Algorithm Accountability Lab (AALab)