I AM A.I. Gradient Descent - an Open-Source Digital Game for Inquiry-Based CLIL Learning

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Abstract

We present an interactive online workshop for K-12 students, which aims in familiarizing students with core concepts of AI. The workshop consists of a variety of resources, inspired by inquiry-based learning techniques, of which we present in detail one module, centered around a browser-based game called "*Gradient Descent*". This module introduces the mathematical concepts behind a gradient descent-based optimization algorithm through the computer game of a treasure hunt at an unknown sea surface landscape. Finally, we report on student feedback for the module in a series of content and language integrated learning in German (CLiLiG) workshops for students aged 14-17 in 30 countries.

Introduction

Artificial intelligence (AI) has developed at an incredible speed in the last years. Thanks to powerful computing technology and available data, fast progress is now happening in a wide range of applications.

The increasing contributions of AI technologies to everyday life and the discussions around the ethical effects of decision-making through AI algorithms have raised the importance of spreading basic knowledge about AI and the techniques behind it to all citizen, both children and adult. This lead to the need for concepts to convey knowledge about AI to these groups.

There is now a huge interest and demand for good tools to introduce core AI concepts to K-12 students to AI and to support K-12 teachers in integrating AI learning experiences into their classrooms (Touretzky et al. 2019; Ali et al. 2019; Tedre et al. 2021). First initiatives include guidelines for K-12 AI education (initiative 2021; Steinbauer et al. 2021), teaching resources showcasing current AI applications or raise awareness of ethical aspects, e.g. of autonomous driving[1]. Interesting research has also been conducted on examining AI learning and teaching at the elementary school level (Lee et al. 2021) or unplugged activities (Long, Moon, and Magerko 2021), just to name a few.

Inquiry-Based Learning

Inquiry-based Learning, also called *Problem-based Learning*, is a student-centered approach to collaborative learning, where students explore tasks alone or in small groups, while teachers serve mainly as facilitators (Dolmans and Schmidt 2006). Problem-based learning was originally formalized as an instructional model for medical schools in the 1960s; however, recent years have seen increasing interest in applying it to K-12 education (McConnell, Parker, and Eberhardt 2016).

Advantages of inquiry-based learning approaches are improved student engagement (Hoffman, Morelli, and Rosato 2019), deeper understanding (Franklin et al. 2015) and increased self-determination (Schmid and Bogner 2017). The approach has some limitations (Kirschner, Sweller, and Clark 2006), e.g. it is not always suitable for students with insufficient prior knowledge, and, if done in the wrong setting, it may result in increased workload and lower basic exam scores (Albanese, Mitchell et al. 1993).

Learning through Gaming

In recent years, both traditional games and computer games have been more and more used for education (Becker 2010; Mogessie et al. 2020), making use of their natural immersive problem solving tasks. Also called *serious games*, they address both the cognitive and the affective dimensions of learning(O'Neil, Wainess, and Baker 2005; Virvou, Katsionis, and Manos 2005) and should facilitate learning for students of different cognitive needs and interests.

The characteristics of computer games can be described as being based on a set of rules or constraints, interactive and providing feedback to players, e.g. through a score (Prensky 2001; Vogel et al. 2006), and directed toward a clear goal that is often set by a challenge (Malone 1981).

A common feature, though not a proper defining characteristic, is a competitive elements, which can be either against the computer, another player, or oneself.

Researchers are still debating on the capacity of serious games to motivate students (Malone 1981; Wouters et al. 2013). For sure, game-based learning environments provide many opportunities to support inquiry-based learning (Mott et al. 2019; Hou et al. 2021), and with inviting settings, expressive characters, and compelling virtual worlds, they create effective and engaging learning experiences (Wouters

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[1]e.g. the moral machine https://www.moralmachine.net/

et al. 2013; McLaren et al. 2017). Recent developments include e.g. language learning-in-culture (Barrett and Johnson 2011), but also computational thinking in the elementary grades (Rowe et al. 2017; Lee et al. 2021) and computer science and AI learning experiences in K-12 classrooms (Buffum et al. 2016; Wang and Johnson 2019).

CLIL Learning

Content and Language Integrated Learning (CLIL) (Coyle, Hood, and Marsh 2010) is a didactic method which combines the teaching and learning of a foreign language with subject teaching and learning.

While a foreign language learned from a language instruction textbook is considered to be artificial[2], as it is rather structured, controlled, and adapted to classroom situations, CLIL education aims to convey language knowledge through a more natural learning environment, resembling first language acquisition. CLIL was introduced first in subject with fewer technical terms and easy opportunities for intercultural learning, i.e. history, geography, social sciences or physical education, but has now propagated to all subjects.

Besides the intercultural benefits, CLIL instruction has proven to be beneficial for learners, as CLIL learners are better at morphology and writing (Zydatiß 2005), and have a greater active vocabulary (Dalton-Puffer 2008), in comparison with regular learners of a foreign language.

CLIL in a school context is often used in specific instruction modules, as most teachers regard only part of the particular content subject syllabus as suitable for CLIL (Huettermann 2013). The exact approach depends on the structure of a country's educational system and different teaching traditions (Wolff 2011) and therefore varies between countries (Beck 2021). English is the predominant language both in conventional foreign language and in CLIL teaching at schools within the European Union (Dalton-Puffer 2011; Eurydice 2006).

CLIL with target language German After English, the most popular languages in CLIL teaching in the EU are French and German. Content and Language Integrated Learning in German (CLILiG) refers to concepts and projects for classes where German is the target language, so not the mother language of the pupils. These are used both for multilingual classes in German-speaking countries, and for schools outside German-speaking countries, which offer German as a foreign language. CLILiG is not only practiced in schools in the EU, but also in universities (2021) and in schools with special focus on the German language worldwide (Pasch Initiative 2021).

An example are the PASCH-schools, where PASCH stands for "Schools - Partners of the Future"(Pasch Initiative 2021), a network of schools worldwide, supported by the German cultural organization *Goethe Institute*.

The Goethe Institute is active in 98 countries as of today (Goethe Institute 2021), and supports about 5-20 PASCH schools per country, depending on the size of the country and the interest in German as a foreign language. PASCH schools offer their students a variety of German teaching and cultural events in German or dedicated to topics of the German culture.

Starting in 2017, we conducted CLILiG immersion workshops on STEM topics with students of PASCH-schools, first on-site, and since 2020 also as fully online workshops. In this paper we describe one of the online educational games we use for our most popular and fully online workshop, entitled "KI erklärt/AI explained". This workshop is part of our larger AI communication and exhibition project I AM A.I.

CLIL instruction in AI learning content and language integrated learning has, to the best knowledge of the authors, not been in the focus of scholars in AI education up to the present. Current use cases containing both the keywords "AI" and "CLIL" rather focus on Computer Assisted Language Learning (CALL) (Dodigovic 2005).

In this work, we describe our first efforts in this direction, which are immersion workshops for students with an intermediate German level. We also conducted some sessions for beginners of German, working with a translator, but we will not report on those special cases here.

General Workshop Setup

We designed two workshop formats: The offline format was designed to take place on-site in a school, the online format is based on a videoconferencing tool.

On-site workshops included not only our learning games, but also unplugged activities, such as discussion cards or a "build your own AI" activity [3], where students can train their own neural network to play the game Nim. Due to the pandemic situation, almost all of our workshops were held in a purely online format, with one facilitator per 8 participants. The standard size was 8 or 16 participants, to ensure personal tutoring and an engaging group experience.

The standard duration of a full workshops is 8 hours, which could be 4 double sessions of 2 hours or 5 sessions of 90min. Usually, the sessions were distributed among several consecutive days, in rare cases weeks.

Resources

For an on-site workshop, tablets, laptops or desktop-PCs are needed. The learning games we developed are all browser-based and run on variable screen sizes, including tablets. Certain applications were additionally enhanced, to adapt to mobile phone displays.

For the online workshops, we used both standard video conferencing tools, and platforms for schools and large conferences. Depending on the tool, the links to open our learning games on each device's browser were embedded, shared in the chat, or we shared a single link list with all games enumerated, so that they could open them when asked to do so.

Our online workshops contained the following learning games:

[2] See e.g. (Beck 2021), page 2

[3] https://www.i-am.ai/build-your-own-ai.html

- *Neural Numbers*: train a neural network to read handwritten numbers
- *Gradient Descent*: look for treasures and discover the gradient descent method
- *Simple Networks*: look inside the mathematics of neural networks
- *Reinforcement Learning*: learn with rewards and punishments in a robot grid world
- *Sumory*: play a game on the exploration vs. exploitation dilemma
- *AI Jam*: make music in an AI piano and drums jam session
- *Ethics of autonomous vehicles*: think along how AI's in autonomous cars should take decisions

In addition, in the on-site workshops, we used the following games:

- *Turing Game Table*: play a board game and discover what is the difference between understanding and knowing
- *Perspective AI*: discuss future AI applications and your role in it

The games and its source code are releases under open licenses, so they can be copied, adapted, and re-used in any educational or commercial contexts. At the moment of writing the paper, we offer free Early Access[4] to all tools upon prior email registration.

As of February 22 2022, the tools will be directly available on the website www.i-am.ai, accompanied by a detailed workshop curriculum.

AI Concepts Addressed

The game *Gradient Descent* addresses the gradient-based optimization method with the same name, which we will describe briefly in the following.

Gradient Descent is an optimization algorithm for finding a local minimum of a differentiable function. In the context of deep learning algorithms, it is used during the training phase of the Neural Network.

By training neural networks, we essentially mean we are minimising a loss function. The value of this loss function gives us a measure how far from perfect is the performance of our network on a given data set.

Our aim is to find those parameter values that minimize the loss function as far as possible.

The Gradient Descent method, introduced already by Cauchy (Cauchy et al. 1847), is usually initialized at random in parameter space and subsequently follows directions of decreasing loss. As this means to follow the (negative) *gradient* of the function as the direction of steepest descent, the method was called "Gradient descent".

This approach lacks a global progress criteria, which leads to descent into one of the nearest local minimum. Since the loss function of deep neural networks is non-convex, the common approach of using gradient descent variants is vulnerable precisely to that problem. To determine how bad this problem is, is still an active research question (Nguyen and Hein 2017; Petzka and Sminchisescu 2021).

Due to its exploration properties, the modification *stochastic gradient descent* will eventually be able to escape from such a region (Goodfellow, Bengio, and Courville 2016). This features is currently not implemented in our game, but is a possible addendum in the future, see section .

Expected Learning Outcomes

The general aim of the workshop, online and offline, is to convey core concepts of AI and Machine Learning algorithms. In an immersive content and language integrated workshop, where facilitators speak only German, students learn these concepts through an educative game, and practice their German in interaction with the games and their peers, both verbally and in writing (on post-its, in the chat, on the whiteboard).

Specifically for the *Gradient Descent* game, which was taught in the middle of the workshop, the learning outcomes are: to understand how the basic Gradient Descent algorithm works, what its issues are and how it connects to finding parameters in a neural network. We expect the participants to discover the method themselves, including random start, step size connected to gradient, or problems with non-convex or very flat loss functions.

Description of the Resource

Gradient Descent is a browser-base game developed by Christian Stussak and Eric Londaits and based on the idea and prototype of Aaron Montag, all team members of IMAGINARY. The game is inspired by the design of early Atari video games of the 80's. It uses very few colours on black background and is based on a vector aesthetics, even using its own vector font.

Features. The game can be played in single-player mode[5], against a bot or in multiplayer mode. Pedagogically, we recommend to first let students try out alone, then discuss the outcomes and ideas of all players, and afterwards continue with the multi-player mode[6] including computer bots for a more competitive experience. The purely browser-based game can be put on full-screen using the rectangle symbol on the top right. The game is customizable via URL parameters to adjust properties as having a menu or only 1 player mode, amount of time per game, amount of trials per game.

The goal of the game is to find the treasure hidden at the deepest spot of the ocean. A boat displayed on the top can be controlled with the arrow keys left/right or the coloured triangle buttons left/right located at the bottom of the screen. With arrow key down or pressing the circular button, the boat releases a probe to the bottom of the ground at the current position. This way, it works with mouse, keyboard or on touch screens.

The immediate feedback of the player is the gradient of the sea ground surface (= loss function) at the point where

[4]https://bit.ly/3h8mPA8

[5]https://www.i-am.ai/apps/gradient-descent-vg/

[6]https://www.i-am.ai/apps/gradient-descent

the probe hits the ground. Through this, the player gradually increases the information he gets on the shape of the ground surface.

The built-in challenge is that, depending on the level, the player either has a certain amount of trials (probes) and/or time to find the treasure.

Aspects of competition. In the multi-player mode, two human players can play at the same time, competing in the treasure hunt. There are three different computer bots available, which can be added to the human player/s. The *easy* bot releasing probes at random positions, the *medium* bot, which applies a standard gradient descent method on its own discovered gradients, adding a random jump if stuck at a local minimum, and the *hard* bot, which takes into account all discovered gradients of all players.

The treasures are represented with funny non-possible mathematical items, i.e. you find the last digit of π. The ocean ground representing the loss function is generated randomly based on certain criteria of smoothness and local minimal. Information on the sea level generation and all source code and configuration details can be found at the game's Github repository[7].

There is an interactive instruction video available at https://www.i-am.ai/virtual-tour.html, choosing the *3 - Gradient Descent video* in the top menu.

Workshop Implementation

The *Gradient Descent* game is introduced by the facilitator in the middle of the workshop, so at session 2 or session 3 in a 4-5 session workshop. Prior to that, students have been familiarized with the concepts of *training* of a Neural Network through the games "Neural Numbers" and "Simple Networks".

The introduction of *Gradient Descent* is accompanied by a short storytelling component, which involves "a pirate lady who lived 300 years ago in the Caribbean and hid an unimaginable treasure at the deepest point of the sea". The story is accompanied by virtual or real pirate costumes, see Figure 1.

Then, the participants play the one player game on their own or in small groups and report the names of the found treasures. After playing several times, the participants are gathered and were asked to describe their strategy or to just to discuss, how they play. Where do you start? How do you react on the gradient discovered? What do you do when you are in a local minimum?

In a next step, the participants are asked to draw their own sea ground, where finding the treasure at the deepest sport is as difficult as possible. Using Zoom, drawing of the ocean floor is done on a collaborative whiteboard. The sequence of the individual steps of the algorithm can also be added by hand drawing to the game.

The multi player game is now introduced. The participants are asked to discover the behavior of the computer bots. The overall Gradient Descent method and its challenges are part of a joint discussion.

[7]https://github.com/imaginary/gradient-descent

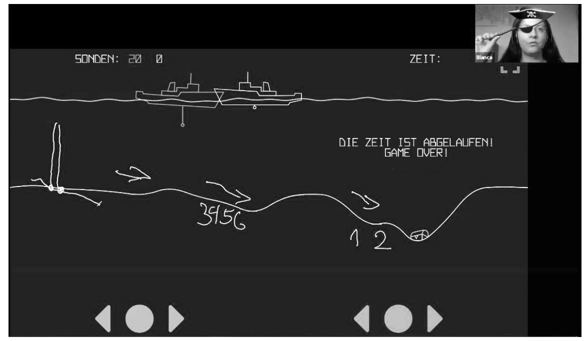

Figure 1. Screenshot of the Gradient Descent Game during an online workshop. The educator uses a virtual pirate costume and enabled collaborative drawing on top of the game screen.

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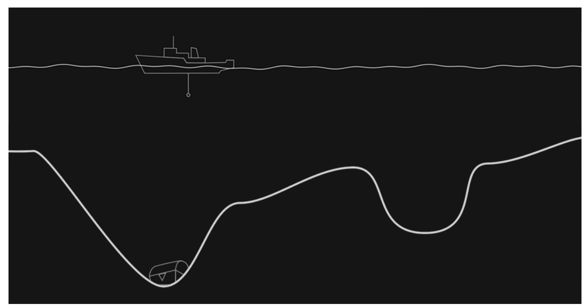

Figure 2. Screenshot of the Gradient Descent Game showing the treasure in a setting with one local and one global minimum.

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A the end, the connection between the loss function and the ocean ground, and the parameters of a neural network and the position of the boat is given by the workshop educators.

Workshop Participants

Participating students came from schools of the PASCH-network(Pasch Initiative 2021), an international network of schools engaged in motivating students to learn German. Schools were spread around 30 countries around the globe, and had very heterogeneous profiles, e.g. some focused on language education, but some also offered more STEM education opportunities.

Students had previous experience with CLiLiG workshops, but little to no prior exposure to CLiLiC activities in STEM subjects. In particular, students were not required to know the mathematical terms of *derivative* or *local minimum*.

Target Age Group and Language Proficiency Level

Participants of our CLiLiG immersion workshops were aged 14-17 and had achieved an upper elementary to intermediate proficiency in German, A2-B1 in the Common European Framework of Reference for Languages (Council of Europe

2021). All participants had actively applied to take part in our workshops through their schools. Some schools hosted our workshops during teaching hours, others as special activities after their normal school day.

Student Learning and Feedback

Student pre-knowledge and pre-workshop expectations As outlined above, students registered by their own motivation. They knew it would be a extracurricular CLiLiG immersion activity about AI, but not more. As the majority of the schools we cooperated with had a focus on language learning, students' main motivation for joining our workshop was often the aspect of practicing their German knowledge in conversation with a native speaker.

In this light, it is not surprising that at the beginning of our workshop, students' answers to the question "where are artificial intelligence products used in our life today?" were quite mixed. On the one hand, many students mentioned autonomous driving, you tube recommendations or chatbots. Other answers indicated that students were identifying the terms "statistics", "data science" and "artificial intelligence": for example, a common answers was "to make statistics", or "to order information".

Even among students from the same city of origin and similar age, the pre-knowledge varied greatly. While some students have had little exposure to technical topics and e.g. were mentioning both answering machines and chatbots as similar technical innovations, other students already have a much clearer picture, mentioning AI products such as virtual assistant systems, automation and digitalization in industrial production or Chess computers.

General Student Feedback

Feedback was collected in written form from students with higher language proficiency, and through 1-click 1-5 star rating for students with less good German skills. In general, our learning games were positively received and achieved an average of at least 4.0 in a 1-5 star rating. The next section discusses this in more detail.

Regarding CLiLiG aspects, students mentioned as very positive the new vocabulary they were exposed to and the possibility to listen to and speak with experts. However, some students felt that the vocabulary used was quite complicated. For example, the English word "probability" reads in German "Wahrscheinlichkeit", which is a difficult word due to its length, pronunciation and orthography. Also, some students wrote that they felt sad about their own difficulties with speaking German in a non-standard classroom situation. Often, the written communication through chat, whiteboard or digital post-its was dominant during the workshops.

Sometimes negative comments appeared on side-conditions, e.g. a sub-optimal workshop time, or various pandemic-related comments, e.g. problems with internet connections, or, for groups who were joining as a school class from their school premises, the obligation to wear facial masks in the classroom.

Regarding *Gradient Descent*, this game received particularly high ratings. Written feedback includes[8]:

I loved this game, because it was interesting to find those treasures!

Many thanks for this informative session, I had a lot of fun and learned a lot.

I really enjoyed it! And I love the pirate hat!

Great! I will show it to my brother as well.

Discussion: Learning through Gaming

The student feedback and their reaction and activeness during the online workshops confirmed both the advantages and disadvantages of inquiry-based learning approaches. To start with an example, our *simple networks* game, a classical problem-based learning task, was perceived as hard and dry, despite it was very easy to play and contains very clear instructions on the task. This game introduces the building blocks of a Neural Network and explains terms needed for training, such as neurons, parameters, and bias. In each level of the game, the player has to find the right parameters for a given mini-network with 3-8 neurons. In this activity, the mathematics was very visible and the educational aspects were greater than the design or gaming aspects: *Simple Networks* contains no special design, no score and no competition, but merely posed a task to find the correct numbers for each parameter.

On the other hand, across all workshops, independent of the pre-knowledge of students, the game *Gradient Descent* was highly appreciated and considered as easy to learn and understand. The pirate and storytelling approach helped to spark curiosity for this module, and humorous scenes, i.e. when all participants found mathematical treasures with their virtual eye patches on, created a positive learning environment and a motivation to continue.

The optics and navigation as an authentic game was perceived as pleasurable and fun to play, and the treasures to be revealed at the global minimum of the loss function provided a reward and motivation to continue.

Participants discovered the basic gradient descent algorithm on their own through playing, which gave them motivation to take part in the discussions, where e.g. issues of local minima were discussed through drawing tricky ocean floors. Some participants reported to our facilitators at the following session that they continued playing after the workshops, either against the computer bots or involving family members.

Our lessons learned from the workshops conducted was therefore that a well-thought game environment increased the motivation of students, while a more classical problem-based learning task with low gaming factor did not.

The open question is, however, how to relate the idea of gradient descent in the one-dimensional case to the very high-dimensional setting of neural networks. This question was occasionally posed by students and answered by the facilitator in a non-technical way, however, we have yet to find a game environment which could convey this better.

[8]Original feedback in German was translated to correct English by the authors.

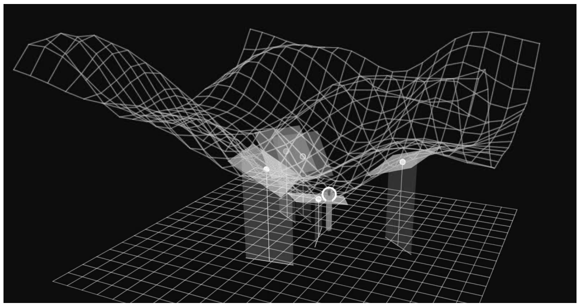

Figure 3. First playable prototype of a two dimensional version of the Gradient Descent game.

We are aware, that this game represents a simplified version of the real gradient descent algorithm and that we took certain decisions to make the game enjoyable. In the real gradient descent algorithm, there is for example no memory of previous steps taken and no prior knowledge of the maximum possible depth.

Conclusion and Future Work

To summarize, the example of the game *Gradient Descent* has shown that it is possible to design an activity which explains a mathematical algorithm, which uses the concept of derivatives, to students who do not have this prior mathematical knowledge. It was furthermore shown that the motivational component of a game is very attractive to K-12 students.

We are now experimenting with offline versions of the game, where students can play on a sheet of paper. This way, the tool can also be used in environments with less digital or tech infrastructure. Additional material, as worksheets, will be added within the project of creating a massive open online course (MOOC), based on our tools. It is a collaboration with the open German AI teaching video platform *KI-Campus*. We did first tests with a two-dimensional versions of the game, see Figure 3, and plan to add variants of the gradient descent method, foremost stochastic gradient descent. A still important open point is how to better connect this game to our other tools, such that we can explain the role of gradient descent inside neural networks in detail and understandable for all. Furthermore, we plan to conduct a quantitative evaluation with the students on the impact of learning via our approach.

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References

Albanese, M. A.; Mitchell, S.; et al. 1993. Problem-based learning: A review of literature on its outcomes and implementation issues. *ACADEMIC MEDICINE-PHILADELPHIA-*, 68: 52–52.

Ali, S.; Payne, B. H.; Williams, R.; Park, H. W.; and Breazeal, C. 2019. Constructionism, ethics, and creativity: Developing primary and middle school artificial intelligence education. In *International Workshop on Education in Artificial Intelligence K-12 (EDUAI'19)*, 1–4.

Barrett, K.; and Johnson, W. L. 2011. Developing serious games for learning language-in-culture. In *Gaming and simulations: Concepts, methodologies, tools and applications*, 1313–1343. IGI Global.

Beck, B. 2021. Pragmatic Competences of German Students in English Content and Language Integrated Learning (CLIL) and Other English as a Foreign Language (EFL) Classrooms. An Explorative Study. *doctoral dissertation*.

Becker, K. 2010. Distinctions between games and learning: A review of current literature on games in education. *Gaming and cognition: Theories and practice from the learning sciences*, 22–54.

Buffum, P. S.; Frankosky, M.; Boyer, K. E.; Wiebe, E. N.; Mott, B. W.; and Lester, J. C. 2016. Collaboration and gender equity in game-based learning for middle school computer science. *Computing in Science & Engineering*, 18(2): 18–28.

Cauchy, A.; et al. 1847. Méthode générale pour la résolution des systemes d'équations simultanées. *Comp. Rend. Sci. Paris*, 25(1847): 536–538.

Council of Europe. 2021. https://www.coe.int/en/web/common-european-framework-reference-languages. Accessed: 2021-09-03.

Coyle, D.; Hood, P.; and Marsh, D. 2010. *Content and language integrated learning*. Ernst Klett Sprachen.

Dalton-Puffer, C. 2008. Outcomes and processes in Content and Language Integrated Learning (CLIL): current research from Europe. In *Future perspectives for English language teaching*, 388. Universitatsverlag C. Winter Programm Heidelberger Verlagsanstalt.

Dalton-Puffer, C. 2011. Content-and-language integrated learning: From practice to principles? *Annual Review of applied linguistics*, 31: 182–204.

Dodigovic, M. 2005. *Artificial Intelligence in Second Language Learning: Raising Error Awareness*. Multilingual Matters. ISBN 9781853598319.

Dolmans, D. H.; and Schmidt, H. G. 2006. What do we know about cognitive and motivational effects of small group tutorials in problem-based learning? *Advances in health sciences education*, 11(4): 321.

Eurydice. 2006. Content and language integrated learning (CLIL) at school in Europe. The Education Information Network on Education in Europe, Directorate-General for Education Youth Sport and Culture of the European Commission.

Franklin, B.; Xiang, L.; Collett, J.; Rhoads, M.; and Osborn, J. 2015. Open Inquiry-Based Learning Elicits Deeper Understanding of Complex Physiological Concepts Compared to Traditional Lecture-Style or Guided-Inquiry Learning Methods. *The FASEB Journal*, 29: 541–22.

Goethe Institute. 2021. https://www.goethe.de/de/wwt.html. Accessed: 2021-09-01.

Goodfellow, I.; Bengio, Y.; and Courville, A. 2016. *Deep Learning*. MIT Press. http://www.deeplearningbook.org.

Hoffman, B.; Morelli, R.; and Rosato, J. 2019. Student engagement is key to broadening participation in CS. In *Proceedings of the 50th ACM Technical Symposium on Computer Science Education*, 1123–1129.

Hou, X.; Nguyen, H. A.; Richey, J. E.; Harpstead, E.; Hammer, J.; and McLaren, B. M. 2021. Assessing the Effects of Open Models of Learning and Enjoyment in a Digital Learning Game. *International Journal of Artificial Intelligence in Education*, 1–31.

Huettermann, A. 2013. Die Eignung lehrplanrelevanter Themen in den bilingualen Sachfächern aus Sicht der Lehrkräfte. In Hollm, J.; Hüttermann, A.; Keßler, J.; Schlemminger, G.; and Ade-Thurow, B., eds., *Taylor & Francis*, volume 19. Landauer Schriften zur Kommunikations- und Kulturwissenschaft.

initiative, A. 2021. https://ai4k12.org/. Accessed: 2021-09-03.

Kirschner, P.; Sweller, J.; and Clark, R. E. 2006. Why unguided learning does not work: An analysis of the failure of discovery learning, problem-based learning, experiential learning and inquiry-based learning. *Educational Psychologist*, 41(2): 75–86.

Lee, S.; Mott, B.; Ottenbreit-Leftwich, A.; Scribner, A.; Taylor, S.; Park, K.; Rowe, J.; Glazewski, K.; Hmelo-Silver, C. E.; and Lester, J. 2021. AI-Infused Collaborative Inquiry in Upper Elementary School: A Game-Based Learning Approach. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 35, 15591–15599.

Long, D.; Moon, J.; and Magerko, B. 2021. Unplugged Assignments for K-12 AI Education. *AI Matters*, 7(1): 10–12.

Malone, T. 1981. What Makes Things Fun to Learn? A Study of Intrinsically Motivating Computer Games. *Pipeline*, 6.

McConnell, T.; Parker, J.; and Eberhardt, J. 2016. *Problem-Based Learning in the Life Science Classroom, K-12*. ERIC.

McLaren, B. M.; Adams, D. M.; Mayer, R. E.; and Forlizzi, J. 2017. A computer-based game that promotes mathematics learning more than a conventional approach. *International Journal of Game-Based Learning (IJGBL)*, 7(1): 36–56.

Mogessie, M.; Richey, J. E.; McLaren, B. M.; Andres-Bray, J. M. L.; and Baker, R. S. 2020. Confrustion and gaming while learning with erroneous examples in a decimals game. In *International Conference on Artificial Intelligence in Education*, 208–213. Springer.

Mott, B. W.; Taylor, R. G.; Lee, S. Y.; Rowe, J. P.; Saleh, A.; Glazewski, K. D.; Hmelo-Silver, C. E.; and Lester, J. C. 2019. Designing and developing interactive narratives for collaborative problem-based learning. In *International Conference on Interactive Digital Storytelling*, 86–100. Springer.

Nguyen, Q.; and Hein, M. 2017. The Loss Surface of Deep and Wide Neural Networks. In Precup, D.; and Teh, Y. W., eds., *Proceedings of the 34th International Conference on Machine Learning*, volume 70 of *Proceedings of Machine Learning Research*, 2603–2612. PMLR.

O'Neil, H. F.; Wainess, R.; and Baker, E. L. 2005. Classification of learning outcomes: evidence from the computer games literature. *The Curriculum Journal*, 16(4): 455–474.

Pasch Initiative. 2021. https://www.pasch-net.de/en/pasch-initiative/ueber-die-initiative.html. Accessed: 2021-09-03.

Petzka, H.; and Sminchisescu, C. 2021. Non-attracting Regions of Local Minima in Deep and Wide Neural Networks. *Journal of Machine Learning Research*, 22(143): 1–34.

Prensky, M. 2001. The games generations: How learners have changed. *Digital game-based learning*, 1(1): 1–26.

Rowe, E.; Asbell-Clarke, J.; Gasca, S.; and Cunningham, K. 2017. Assessing implicit computational thinking in zoombinis gameplay. In *Proceedings of the 12th International Conference on the Foundations of Digital Games*, 1–4.

Schmid, S.; and Bogner, F. X. 2017. How an inquiry-based classroom lesson intervenes in science efficacy, career-orientation and self-determination. *International Journal of Science Education*, 39(17): 2342–2360.

Steinbauer, G.; Kandlhofer, M.; Heintz, F.; Chklovski, T.; and Koenig, S. 2021. Education in Artificial Intelligence K-12. In *KI - Künstliche Intelligenz*. Springer.

Tedre, M.; Toivonen, T.; Kahila, J.; Vartiainen, H.; Valtonen, T.; Jormanainen, I.; and Pears, A. 2021. Teaching Machine Learning in K–12 Classroom: Pedagogical and Technological Trajectories for Artificial Intelligence Education. *IEEE Access*, 9: 110558–110572.

Touretzky, D.; Gardner-McCune, C.; Breazeal, C.; Martin, F.; and Seehorn, D. 2019. A Year in K-12 AI Education. *AI Magazine*, 40(4): 88–90.

University, P. U. o. B.; and Economics. 2021. http://ue.poznan.pl/en/news,c16/news,c15/clilig-project-recognised,a53006.html. Accessed: 2021-09-04.

Virvou, M.; Katsionis, G.; and Manos, K. 2005. Combining software games with education: Evaluation of its educational effectiveness. *Journal of Educational Technology & Society*, 8(2): 54–65.

Vogel, J. J.; Vogel, D. S.; Cannon-Bowers, J.; Bowers, C. A.; Muse, K.; and Wright, M. 2006. Computer Gaming and Interactive Simulations for Learning: A Meta-Analysis. *Journal of Educational Computing Research*, 34(3): 229–243.

Wang, N.; and Johnson, M. 2019. AI education for K-12: Connecting AI concepts to high school math curriculum. In *Proceedings of the Workshop on Education in Artificial Intelligence K-12 held in conjunction with IJCAI-2019*, 15–19.

Wolff, D. 2011. Der bilinguale Sachfachunterricht (CLIL): Was dafür spricht, ihn als innovatives didaktisches Konzept zu bezeichnen. In *www. forum-sprache. de*, 75.

Wouters, P.; Van Nimwegen, C.; Van Oostendorp, H.; and Van Der Spek, E. D. 2013. A meta-analysis of the cognitive and motivational effects of serious games. *Journal of educational psychology*, 105(2): 249.

Zydatiß, W. 2005. Einleitung: Sachfachlicher Kompetenzerwerb im bilingualen Sachfachunterricht. In Bonnet, A.; and Breidbach, S., eds., *Didaktiken im Dialog*. Peter Lang.