Playing Go in an integrated Mathematics and Computing course[1]

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v2018.11.26 DRAFT at 09:39

Abstract

Acquiring knowledge in Mathematics and Computing is increasingly needed in almost all areas of study. It is difficult to motivate these subjects for students in other majors. One reason for the disinterest could be the lack of naturally arising questions, for which the students genuinely seek answers. Playing Go can provide such a shared base experience, where the game itself is the source of motivating problems.

Here we describe the incentives for, and the design decisions in developing an integrated artificial intelligence course centred around the game. By its own logic, this potent combination leads to self-reflection and metacognition techniques. Transferring these skills could also help students in other subjects.

Go players are keen on reasoning for the benefits of playing the game, since we have a tendency for sharing what we enjoy. This paper can be viewed as such an argument, with a special focus on education.

Due to rapid technological and societal changes, education on all levels, admittedly or not, is in deep crisis [6]. The main question is how to prepare students for their future life. No one can predict the future job market. Still, there are some short-term strategies (teaching what is needed at the moment, e.g. mathematical and computing skills) and long-term ideas for nurturing skills for coping with constant change. We will address both issues. First we try to identify a main factor contributing to current failures in mathematical and computational subjects.

Motivating studies

Learning could be effortless if someone has a genuine interest in a subject. We take this everyday observation as our main assumption for improving the teaching and learning process in an undergraduate mathematics and computing course.

[1] For more information, visit the website of the course at `https://egri-nagy.github.io/igomath/`.

External motivation does not transfer to internal

Students may be very well motivated in their studies, e.g. preparing for an entrance exam or working towards a degree. However, these external incentives may not automatically become everyday interests in particular subjects. Courses in mathematics and computing are particularly prone to this type of failure. External pressures are high for passing standardized tests, while mathematics is not a subject loved by many. Getting attractive, high-paid software engineering jobs does require expertise in programming, which is usually hard-earned by countless hours of coding. Without enjoying these activities, studying then becomes a painful activity, loosing much of its efficiency. These subjects can be difficult to master for the students without a genuine interest in symbolic languages and in the inner workings of computers.

Similar problems arise from the educator's perspective. It is not efficient to teach someone a method of solving a problem, who does not happen to have that particular problem. It is also not exactly a nice thing to do, since it often involves exercising power to force the person to pay attention. Still, traditional mathematics education works mostly this way. The assumption is, that the algorithms we teach will be useful for the students at some later stage of their studies, or in subsequent professional work. However, it is a bit like selling a useless product to a customer. Note, that the salesperson could be honest and convinced about the utility of the item, nonetheless the situation is damaging. In education, the price we pay is students' time and suffering. And again, this happens often despite the good intention of teachers.

Computing is in a better position in terms of motivation, as it is conspicuously pervasive in our everyday life. Mathematics built up a false image of itself, and it is usually perceived totally disconnected from life. However, topics in computer science may be loosing its immunity against indifference. The success of technologies may suggest that there are no problems to solve any more. For instance, explaining the PageRank algorithm to students born after Google requires depicting the age of Internet search where the relevant page was usually somewhere at the bottom. Well functioning software tools could diminish the desire of understanding their underlying logic.

Creating motivating situations

Therefore, we have to create situations in the classroom, in which questions spontaneously arise, when students face a real problem themselves. They need to meet a natural difficulty, preferably the same obstacle for everyone to make group work and collaboration possible. Then, we can deploy methods for obtaining solutions; either just giving them away, or even better, leading the students to discovery. This is of course not a secret wisdom, anyone serious thinking about teaching will have this insight. The real issue is the next step. *How to create motivating situations?*

Playing games

Playing games is an integral part of our culture [1,7]. Somehow we like challenges, and willing to do the effort when playing games. It is also a way of social interaction, an activity humans are specially evolved for. Education can leverage games by tapping into this natural willingness and propensity. To develop and maintain physical fitness we can do team sports. For sharpening the mind we can use board games. Now we can ask our question more precisely. *What game can we use to motivate studying mathematics and computing?*

The remarkable properties of Go

For developing thinking skills by playing games we have a wide range of choices. The selection can be quickly narrowed down to traditional strategy board games, if we require a wide spectrum of expertise, i.e. the game cannot be mastered by humans in a short time. Chess and Go stand out for their educational benefits and for being the driving challenges for the development of Artificial Intelligence. They are both suitable for our purpose of building a course. Here we choose the game of Go has some unique properties; not to mention the recent surge in wider scientific [11] and public interest due to AlphaGo's breakthrough [17].

Go is abstract and complex

Abstract means that unnecessary details are removed, something can be defined in a succinct way. The rules of Go can be described in a couple of sentences. Nothing from the rules can be omitted without destroying the game. Due to being non-specific, abstract implies that it can be related to a wide range of other things. Chess is also an abstract board game, but on a different level. It is tied to kings and their armies, which of course still leaves plenty of possibilities for connecting to real life [10]. We could leave out some of its rules (e.g. not including the bishop), which would give a different, but still chess-like game.

Complexity comes from the interactions of the simple parts of a system [13]. A complex phenomenon is interesting, since we cannot summarize it with a single idea, thus we cannot master it in one shot. In Go, complexity arises from the interaction patterns of the stones on the board.

Adding these two together, we conclude that Go is potentially connected to many interesting complex phenomena. This gives the opportunity: *insights gained in Go could be transferred to other fields of knowledge*. This is the single general argument for playing Go in educational settings. The research question is about how exactly this knowledge transfer can be done or facilitated.

As a concrete example, we can consider the incomprehensible combinatorial chaos of Go [21]. We 'live' in a tiny part of these vast possibilities. A meaningful game between two people is a rare occurrence. Creative competition is a human endeavour, that is where we feel home. Beginners very quickly learn to distinguish between a random position and the snapshot of a game. This parallels how we are at home in the universe. Only some very special configuration of material, e.g. the surface of a planet with a protective atmosphere is habitable for us. Random arrangement of particles does not give rise to starts and galaxies, planets and life.

A game is a smaller version of our struggle for survival and prosperity [22]. Natural disasters are moves by a formidable opponent, but the consequences of our own actions often catch us too.

On the board the arrangements of stones build up the emergent structures we talk about when discussing the game. Individual stones do not matter, only their relationships. This is exactly the basic tenet of category theory, the 'mathematics of mathematics' [2]. Also, the objects of our world is built up from combinations of elementary particles and atoms via the interactions between them. It is often remarked the number of positions on the full board is way bigger than the number of atoms in the universe. This comparison is unfair to the universe. The correct way would be using the number of all possible configurations of matter in the observable universe". Constructing any desired configuration of atoms, "transforming *anything into anything* that the laws of nature allows" [3] is the ultimate goal of engineering. On the board, when the two players cooperate, a large fraction of the space of all legal positions can be visited [21].

Therefore, in a very abstract sense, the game is really a model of the universe. This is a grandiose metaphor, which can be exploited both for sciences and for the game. It also fits into a long tradition of using the go board to represent many things, like the four seasons, the stars. Its abstract nature allows the game to symbolize anything that is important in a given age. The distinction between order and randomness permeates several branches of science. It is a fundamental issue even when the uniqueness and finiteness of the universe is questioned [19].

Thinking is unavoidable in Go

One of the most common observations about the game is that "It makes you think." [16]. When you play, some questions are inevitable. The immediate ones are about a particular game. *How do I make territory here? How should I protect my group?* Then there is reflection on playing and improving on a larger timescale. *How can one become a better player? Is there a sure winning strategy? What does it mean to be strong?* and so on. We can rely on the appearance of these questions in the players' minds. Moreover, the answers contain a fair amount of mathematical reasoning, most notably combinatorics, game theory and probability theory. This is an ideal setup to teach general problem solving heuristics is [14], in the context of the game [4]. Therefore, the game is ideal candidate for a 'real-world' problem introduced in the classroom. As the rules are easy to learn, and it doesn't take too long to have a meaningful experience of elementary tactics and strategies, Go could give a shared background knowledge for everyone in the class. This does not imply that everyone has to be on the same playing level.

A course, where everyone has a direct experience of the problem could alleviate one of the biggest problem of teaching mathematics and computing in a liberal arts curriculum. Students do not have a uniform background knowledge in these subjects.

The positive role of Artificial Intelligence

It is hotly debated how AI technologies will change our lives for better or worse. Considering all possibilities is an immense task [20]. Here we focus on the short term benefits.

AI as a mirror

Thinking is our most important ability. Therefore, improving it is also critical. How can we improve our thinking? We have to think about our thought processes, reflect on them.

The advance of AIs in Go could be viewed as something difficult to swallow. However, some techniques are vindications of human thinking. They are often modeled after our thought processes. Logical thinking in solving a life-and-death problem is made precise in search algorithms. Intuition is modeled by decisions of neural networks. They justify our best learning method, playing and replaying games a lot improves playing strength.

On the other hand, randomized algorithms, like random playouts in Monte-Carlo tree search are not something we can do even if we wanted to. This prompting us to develop a better sense for probability and statistics.

AlphaGo found a way to integrate the wisdom of human masters into a convenient 'search engine' for the next move [17]. This is putting the knowledge of all masters into a different container. Playing against AlphaGo is playing against every masters, not just a single opponent. AlphaGo Zero, could reconstruct, and surpass all human wisdom in three days [18]. It is a bit like that in Go we failed as a species to fully understand the game. However, thinking that we had already discovered everything that can be known about the game is overconfident. We tend to put ourselves into a privileged position, as a final goal of evolution. This is of course far from the truth [5].

In a way AIs provide a mirror for us. We can look into it and see ourselves, or rather we can see our improved selves.

AIs as democratizing force

Beyond teaching, another beneficial use of AI go engines is that it makes learning to game easier for everyone. There is always a strong player ready to play. It's like printing press, knowledge is more democratically distributed, allowing everyone to enjoy the game more. The same happened in the world of chess [9].

It is more important to provide access, not just to the game, but for the AI technologies themselves. This is the role of university courses.

Knowledge transfer

Transferring skills between Go and mathematics or computer programming is not a straightforward process. As pointed out in [12], professional Go players often know little about Mathematics since their education was focused solely on the game from early on. The conclusion is clear: in order to play well, there is no need for Mathematics. While in Europe, with no professional system, Go players are typically mathematicians or software engineers, hinting that these might be related skills. In Europe people are often introduced to the game during their studies at university. However, these observations provide little insights about the possible connection.

In any case, the transfer between the game of Go and Mathematics cannot be direct. Mathematics is a symbolic language, and Go is not. However, when we look at the thought processes involved in both fields similarities arise. The expertise is built by transitioning through practice from a conscious step-by-step calculation process to a more automated, but mostly unconscious pattern recognition ability. Like solving a tsumego problem by figuring out what move to choose next, the simplification of a logarithmic expression in algebra is about finding the right next move, i.e. choosing the appropriate law of logarithm. In both cases the trick is to choose suitable action from a set of possibilities.

To improve this decision making process, the interaction between calculation and intuition can be improved by being aware of their capabilities [8]. Therefore, we suggest that the transfer could happen on the level of metacognition. That is, the need for improving when playing games enforces self-monitoring. Then, this can be transferred to mathematical problem solving, where it is generally thought to be beneficial [15]. *Metacognition* is the defining core of classical heuristics [14]. The strong game review culture of Go [22] is an implementation of these principles.

To promote self-reflection the course will contain writing and oral presentation components. These will be about game reviews and tsumegos. Also, studying artificial intelligence, and comparing it to natural intelligence could help developing metacognitive skills.

Summary

The game of Go is a promising way for teaching discrete mathematics, statistical and computational thinking, subjects that are in need today. Moreover, the capability of self-reflection and mental resilience will surely be needed to cope with accelerating societal changes.

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