

# Is Constructivism Sufficient for Teaching? Experience of Machine Learning Says “Not Always”

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## 1. What is constructivism in education

- Education needs to take into account that our memory is not perfect:
  - if we are simply asked to remember a rule or an algorithm,
  - there is a high probability that we will forget it when time comes to use this rule.
- So, to make sure that students can still recover the rule when needed, a natural idea is to provide them:
  - not just with the rule itself,
  - but also with a lot of additional material from which the students can later derive the rule – even when they forget the rule itself.
- It is also desirable to make sure that the students can reconstruct the rule even if they forget some part of this additional information.
- What kind of additional information is available?
- To answer this question, let us recall how general rules for solving a class of problems are formed.

## 2. What is constructivism in education (cont-d)

- Usually, at first, we have solutions to individual problems.
- When many such solutions have been accumulated, people notice that there is a general pattern in all these individual solutions.
- Thus, a general rule is formulated.
- So, a natural idea is to teach not only the rule itself, but also examples that can lead to this rule.
- This is usually done in teaching, but in many cases, the examples are given *after* the rule has been formulated.
- The problem with this approach is that when the students already know the rule:
  - they will not pay much attention to specific examples, and
  - they will most probably not understand how these examples generalize to a general rule.

### 3. What is constructivism in education (cont-d)

- So, it looks like a better idea is:
  - to *first* teach the examples – selected in such a way that it will be reasonably easy to extract the rules from these examples,
  - and only after that teach the rule.
- Actually, an even better idea is *not* to teach the rule.
- Instead – since it is easy for the students to derive this rule – we should let the students themselves form this rule based on the examples.
- This way, they will go through an experience of deriving the general rule.
- So, they will have some memories of what and how they did it.
- These memories will help them derive the rule next time – when they have forgotten the rule but still remember some of the examples.

#### 4. What is constructivism in education (cont-d)

- In this approach, the students *construct* the rules themselves.
- So this approach to education is known as *constructivism*.

## 5. Comment

- This term may be somewhat confusing to many mathematicians.
- The reason is that in mathematics, the same word *constructivism* is used to describe:
  - a direction of mathematical research
  - when we limit ourselves only to objects and relations that can be actually constructed.
- For example, instead of considering all possible real numbers, we only consider real numbers  $x$  for which there is an algorithm that:
  - given a natural number  $n$ ,
  - computes a rational number  $r_n$  which is  $2^{-n}$ -close to  $x$ .
- Constructivism in education is different, but methodologically, it is a very similar idea.
- We limit ourselves to concepts and rules that can be constructed – this time, constructed from examples.

## 6. Successes of constructivism in education

- Constructivism is, at present, one of the main directions in pedagogy.
- Many studies has shown that its use leads to more effective learning
  - when:
    - in the long term,
    - students can recall and use a larger part of their knowledge.
- Moreover, this direction encourage researchers and practitioners to come up with a natural way to derive the existing rules – even those rules that, at first, sound like weird tricks.
- These efforts has made several rules and algorithms more natural.
- This is similar to constructivism in mathematics:
  - in mathematics, constructivism helped to come up with new algorithms for computing different important mathematical objects,
  - and thus led to important practical applications.

## 7. Indirect machine learning support of constructivism in education

- The main ideas behind constructivism in education seems to be strongly supported by the current spectacular successes in AI.
- In the past, most AI was focused on teaching rules to a computer system.
- This approach started with initial successes that encouraged optimistic predictions – that we will soon have:
  - chess-playing computers and thinking robots,
  - computers translating from one natural language to another,
  - talking to the users in natural languages, etc.
- Unfortunately, with rules-based AI, these predictions did not materialize.

## 8. Indirect machine learning support of constructivism in education (cont-d)

- Instead, all these goals were achieved when researchers decided:
  - instead of teaching rules to a computer,
  - to simply give the computer examples – from which the computer can reconstruct the general rules.
- This AI approach is known as *machine learning*.
- There are many spectacular successes of the machine learning approach.
- This seems to indicate that a similar constructivism approach to human learning is more effective than teaching the rules to the students.

## 9. (Indirect) Doubts

- All three authors are instructors.
- We are using the constructivism approach as much as possible.
- In many cases, we have seen that using a constructivism approach has improved students learning.
- However, there seems to be some problems – probably caused by overusing this approach.
- These problems have occurred when one of us (VK) has been teaching two theory of computation classes:
  - a graduate one
  - and an undergraduate one (called *Automata*).
- Both classes involve several complex and not-easy-to-justify rules and algorithms.

## 10. (Indirect) Doubts (cont-d)

- These classes are not about memorization.
- They are about using the learned skills to come up with new applications of the algorithms and of the proof ideas.
- To avoid the need to memorize the material by heart:
  - on each test,
  - the instructor allows students to have a few-page “cheat sheets” that they can prepare beforehand.
- The instructor’s advice is to use these cheat sheets to write down the needed rules and algorithms – and also examples of their applications.
- Many students do it, and most of these students perform very well on the corresponding tests.
- However, many other students, in the spirit of constructivism, only place examples of their cheat sheets.

## 11. (Indirect) Doubts (cont-d)

- These students think that they will be able, during the test, to reconstruct the rules from these examples.
- In general, the overall performance of these students is much worse.
- The performance of the students who explicitly write down the rules on their cheat sheets is much better.
- There was no such drastic difference in many other classes, where rules and algorithms are not as complex.
- Thus, the need to teach rules is probably a phenomenon explicitly related to the complexity of the material.
- All this has made us think that:
  - maybe in some cases,
  - constructivism approach needs to be supplemented with a more traditional teaching-rules-first approach.
- How can we check whether this is a good idea?

## 12. (Indirect) Doubts (cont-d)

- As we have mentioned, a large amount of support for constructivism approach comes from the current machine learning successes.
- So, we decided to look into whether in some cases, machine learning experience has shown a similar need for:
  - teaching rules
  - in addition to providing examples.

### 13. And indeed, there are examples when also teaching rules helped machine learning

- We immediately found several studies that show that in some cases:
  - also teaching rules – and/or incorporating rule-based techniques like stacks into a neural network
  - helps machine learning.
- Interestingly:
  - most of these examples were related to reasonably complex rules and algorithms,
  - rules and algorithms of the type that we teach in theoretical computer science classes.
- Another example is that the use of fuzzy rules helps machine learning.

## 14. Conclusion

- Both the experience of our own teaching and an experience of machine learning show that for complex topics:
  - it is beneficial to sometimes supplement the constructivism examples-first approach
  - with a more traditional rules-first approach.

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