Notional Machine in Mathematics and Introductory Computer Science Courses

Eamon Worden
Grinnell College
Grinnell, United States
wordenea@grinnell.edu

Olivia Song
Grinnell College
Grinnell, United States
songjunt@grinnell.edu

Peter-Micheal Osera
Grinnell College
Grinnell, United States
osera@cs.grinnell.edu

ABSTRACT

Notional Machines (NMs) are a pedagogical device used by teachers in order to help students understand certain concepts. While NMs have been cataloged, the effectiveness of NMs has been rarely evaluated. We build upon this research by exploring what makes certain NMs more effective in various computer science and mathematics courses. We interview professors and students to assess NMs used in the classroom. Notably we found that most students are able to employ the NMs introduced by their professors, and that introductory students prefer template-like NMs, whereas upper level students rely on more conceptual NMs.

ACM Reference Format:
Eamon Worden, Olivia Song, and Peter-Micheal Osera. 2023. Notional Machine in Mathematics and Introductory Computer Science Courses. In *Proceedings of the 54th ACM Technical Symposium on Computer Science Education V. 2 (SIGCSE 2023), March 15–18, 2023, Toronto, ON, Canada.* ACM, New York, NY, USA, 1 page. https://doi.org/10.1145/3545947.3576324

1 PROPOSAL

Notional Machines (NMs) are a pedagogical device used by teachers in order to help students understand certain concepts. They often include visual components, analogies, or simplifications which help students form a conceptual models of underlying domains. First introduced as "the idealized model of the computer implied by the constructs of the programming language" [1], NMs within computer science have held roughly the same definition since. In more recent studies there have been many catalogues of NMs, some studies into when NMs are used, and a few studies on mental models used by students. A study at ITiCSE 2020 [2] looked into the literature on NMs that had been done since their inception and catalogued 57 NMs used by various professors.

One observation noted in the literature [2] that we also discovered was that the effectiveness of NMs was rarely evaluated. NMs were often introduced and explained, but rarely supported the claim that they were effective with evidence. We build upon this research by exploring what makes certain NMs more effective in various computer science and mathematics courses.

Following a literature and textbook review where we found NMs in textbooks differ significantly from those used in classes we interviewed six professors, in computer science and math, to get their thoughts on NMs and discuss which NMs they choose to employ. Each gave examples of NMs and discussed when and why they employ NMs during lectures. They generally favored NMs which they felt had a strong explanatory power to time ratio. We also observed their classes and observed NMs which, when asked about, they sometimes said they didn't realize they were NMs.

For the interviews with students, we gave four problems that were similar to the problems in their exams or textbooks, and had them walk us through their thought process. Then we asked questions about whether they used NMs introduced in class when solving the problems and if NMs were supporting their thinking process and the understanding of concepts. In addition, we asked for advice they had on how the NMs can be improved to offer better help. A majority of students were good at employing NMs. It is also noticeable that introductory students were especially effective with template-like NMs, while upper level students preferred more representation or analogy based NMs. NMs which were used more often in class were significantly more used by students. In addition, NMs that helped most in students' understanding were often built on other NMs, included visual components, and were easier for students to apply to problems.

In introductory computer science courses, the most commonly used NMs by students were template-like, such as code tracing. They used representation based NMs on more difficult and abstract problems, such as with linked lists, and they have used this kind of NM frequently during the process of concept internalization as well as problem solving. In upper level courses students would use more representation and analogy NMs learned in class to help understand difficult concepts, such as graphs or deterministic finite automata. Noticeably, how students solved problems varied significantly more than introductory students, suggesting they were not using a template-like NM for solving problems.

In the future we hope to further explore and elaborate on the fine grained details of which NMs are effective at different times. We hope to explore further the differences in template-like NMs, representation-based NMs, and analogy based NMs, particularly in when they can be most effectively employed. We also hope to look further into hierarchical and otherwise NMs as often times those NMs seems to be significantly more effective and employed than others.

REFERENCES

[1] Benedict Du Boulay, Tim O'Shea, and John Monk. 1981. The black box inside the glass box: presenting computing concepts to novices. *International Journal of man-machine studies* 14, 3 (1981), 237–249.

[2] Sally Fincher, Johan Jeuring, Craig S Miller, Peter Donaldson, Benedict Du Boulay, Matthias Hauswirth, Arto Hellas, Felienne Hermans, Colleen Lewis, Andreas Mühling, et al. 2020. Notional machines in computing education: The education of attention. In *Proceedings of the Working Group Reports on Innovation and Technology in Computer Science Education.* 21–50.

SIGCSE 2023, March 15–18, 2023, Toronto, ON, Canada

ACM ISBN 978-1-4503-9433-8/23/03.
https://doi.org/10.1145/3545947.3576324