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Towards a Model of Progression in Computational Empowerment in Education

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Abstract

In this paper, we present a model for progression in computational empowerment in education. Computational empowerment (CE) expands computational thinking (CT) by adding a focus on empowering citizens to critically engage with technology, but currently lacks an articulation of what characterises progression towards CE. Through combining aims from computational thinking with computational empowerment, and structure progression using the SOLO taxonomy, we take the first steps towards a model for understanding and articulating progression in computational empowerment. The model has been applied in the analysis of four CE-focused research projects. Based on the analysis, we propose that computational empowerment is a matter of reaching a high competency level regarding computational concepts, computational practices and reflexivity regarding the effect of technology in one’s own life and in society. Finally, by formulating examples of learning goals, we illustrate how the model can be used by teachers and researchers to articulate, determine and compare CE learning goals, so that learning goals are aligned and complement each other from one stage to the next.

Keywords: Computational Thinking; Computational Empowerment; education.
1. Introduction

Computational Thinking (CT) [1] has been widely recognised as a way to encourage new generations to create technology and to pursue careers in STEM subjects (science, technology, engineering, and math). However, in recent years, CT has been criticised for being too narrowly focused on developing students’ technical and generative skills, and for neglecting critical skills for students to decode the role of technology in our everyday lives and society [2]. This critique has led to multiple proposals for expanding CT to encompass broader, more critical perspectives [3, 4].

One of these proposals is Computational Empowerment (CE) [3, 5]. Dindler et al. [5] defines CE as “the process in which children and youth, as individuals and groups, develop the skills, insights, and reflexivity needed to understand digital technology and its effect on their lives and society at large, and their capacity to engage critically and curiously with the construction and deconstruction of technology”. The authors demonstrate, through digital fabrication activities in a Danish school context [6], how CE might look in practice, but provide limited reflections on how successful these activities were in computationally empowering the participants. They find that students improved their understanding of digital fabrication technologies, gained hands-on experience with digital fabrication technologies, found the work with such technologies motivating, and had initial signs of design literacy; the competencies to work “creatively with technology, and complex problem solving” [6].

However, Dindler et al. [5] and Iversen et al. [3] do not provide much analysis of the relation between the results and the activities that might be used to inform future learning activities and interventions. We argue, that if CE is to gain traction, researchers and teachers first need ways to relate the aims of CE with specific learning goals. Tools, methods, and practices for teaching and assessing design and programming are quite well developed, but the same cannot be said for teaching and assessing children’s abilities to analyse, understand and critically reflect on the role of technology, especially when it comes to resources.
that teachers can use in their daily practice [5]. While CE is clearly defined in
terms of its agenda and goals, it is less clear what steps teachers need to take,
to take students from being users of technology to becoming computationally
empowered citizens. This has led us to formulate the following research question:

RQ: What characterises progression in computational empowerment in educa-
tion?

In this paper, we take the first steps towards a model of progression in CE
that allows researchers and educators to articulate learning goals in compu-
tational empowerment that are aligned and complement each other from one
stage to the next. We do so by analysing four on-going research projects, which
all adhere in some way to the CE agenda. For the analysis, we developed an
early model for relating concrete learning goals to progression in CE, by com-
bining aspects from CT, CE, and the learning sciences. We found that while
the model was not able to provide an all encompassing analysis of the research
projects, it provided the involved researchers with a language to express how
their projects align with CE. In addition, the analysis allowed us to compare
and discuss strengths and shortcomings of the research projects across different
aspects. Finally, we suggest that it can help design new activities and projects
based on the CE agenda.

The paper is structured in the following way: First, we present work related
to what characterises CT and CE skills as well as progression in teaching. Next,
we present the CE progression model. Subsequently, we apply it to four research
projects to exemplify how it is useful as an analytic tool. Finally, we discuss
the use of the model both as an analytic as well as a generative tool.

2. Related Work

In order to move towards a model of progression in CE, in the following, we
present work related to characterising computational skills and progression in
learning activities for children and young people.
2.1. Characterising Computational Skills

The notion of computational empowerment has recently grown out of a need to address limitations in conceptions of CT in terms of its lack of focus on the wider implications of the role of technologies in society and personal lives [3] [7]. Kinnula and Iivari [7] makes the point that even though projects seek to support empowerment, this might imply different perspectives including functional, educational, democratic and critical perspectives. Encompassing these perspectives Iversen et al. define three core aspects of CE [3]: “1) engaging creatively in technology development, 2) understanding the role of digital technology in society, and 3) reflectively and critically understanding the role of technology in one’s own life.”. The first aspect encompasses traditional CT skills, which multiple authors have tried to characterise. Wing’s own conceptualisation of CT [1, 8] consists of several aspects including problem reformulation, recursion, problem decomposition, abstraction and systematic testing, which all relate to the first aspect of CE outlined above. Similarly, Perković et al. [9] present a framework for CT, which they base on Denning’s principles of computing [10]: computation, communication, coordination, recollection, automation, evaluation and design. They argue that to develop a full CT curriculum, these principles should be addressed.

Weintrop et al. [11] introduce a taxonomy of CT (for mathematics and science) consisting of data practices, models and simulation practices, computational problem solving practices and systems thinking practices. Barr et al. [12] include data organisation, data analysis, automation, efficiency and generalisation while Bers et al. [13] include abstraction, generalisation, and trial and error activities.

Common for these frameworks is, that they focus on computational concepts and practices related to computing, and little on the wider perspectives on technology related to the implications of the use of digital technology for personal life as well as society, the second and third aspect of CE mentioned above. Adopting a wider perspective, Brennan and Resnick propose three key dimensions of CT, namely computational concepts, computational practices and
computational perspectives. Concepts refer to concrete computational aspects such as abstraction, automation and so forth. Practices refer to the practices programmers develop as they work with e.g. general problem solving skills and data practices. Together, concepts and practices encompass the CT skills presented above, and focus on allowing students to engage creatively in technology development, i.e. the first aspect of CE. Unlike other CT frameworks, Brennan and Resnick go beyond this and introduce perspectives as a set of skills leading to "a shift in the understanding of oneself or the world" similar to the more reflective second and third aspects of CE. As an example, to assess students working with Scratch (so called Scratchers) against these concepts, Brennan and Resnick propose three approaches; project analysis, artefact-based interviews, and design scenarios. They find, that while the three approaches are able to effectively assess the students’ knowledge and use of computational concepts and practices, they are not effective at evaluating perspectives, and it seems they struggle in defining exactly what role perspectives should play in CT.

To summarize, both Iversen et al. [3] and Kinnula and Iivari [7] have quite broad understandings of CE related to the wider implications of digital technology, but represent a more narrow conception related to technology development, whereas the more CT-oriented perspectives have vague conceptions relating to the wider implications of digital technology but quite rich conceptions relating to the creation of digital technology. But none of these conceptions of CE have notions of progression. We argue that in order to move towards a model for learning goals and progression for computational empowerment, CE and CT approaches should be brought together, but also be complemented with notions regarding progression in learning activities.

2.2. Characterising Progression in Learning Activities

A key challenge in teaching computational thinking is supporting progression of knowledge [15], and even more so in computational empowerment. A learning progression is a sequence of subskills that needs to be mastered to
reach a curricular aim \[16\], and is characterised by starting with something simple and moving on to something more advanced, applying the knowledge in new ways. Learning is an individual activity: each of us learns at a different pace and has different cognitive abilities \[17\]. Thus, progression can be hard to measure, as it includes both cognitive and more observable processes. In mathematics, progression is characterised by learning one new concept while building on understanding the previous concept \[17\]. However, we do not yet know much about what characterises the development from basic to complex forms of many of the 21st century skills such as computational thinking \[18\], and even less so CE. Thus, we do not yet have a model of best practice for how to guide teachers in what to expect from learners at different levels of skill, and how they can make progress.

We see a shift in what learners need in order to fulfil their potential, from the previous focus on knowledge, skills, and competencies \[19\] to a focus on knowledge, skills, attitudes, and values, meaning encompassing not only knowing and doing, but also becoming \[20, 21, 22\]. Attitudes and values are an acknowledgement that competencies are more than knowledge and skills. They refer to the principles and beliefs that influence one’s choices, judgements, behaviours, and actions in regards to the individual, society, and environment. This is aligned with the thinking behind computational empowerment, where perspectives on one’s own life and on society are vital aspects, and where critical thinking is a major driver.

Hattie raises attention to the need for setting challenging learning intentions, being clear about what success means, and an attention to learning strategies for developing conceptual understanding about what teachers and students know and understand \[23\]. However, in defining and analysing the goals of a specific activity, a general structural framework for evaluating learning outcomes can be useful as it enables us to compare learning goals between different subject areas and learning activities. One taxonomy based on the outcome of teaching is the Structure of the Observed Learning Outcome (SOLO) \[24\]. The SOLO Taxonomy is a five-tier hierarchical framework for structuring learning outcomes.
“SOLO describes a hierarchy where each partial construction [level] becomes a foundation on which further learning is built” [24, p.41]. The SOLO taxonomy differs from, e.g., the BLOOM taxonomy in being based on observable outcomes rather than internal cognitive processes [25, 24]. The goals of the SOLO taxonomy include providing a tool for defining curriculum objectives, intended learning outcomes, and evaluating learning outcomes based on these objectives [24]. The SOLO taxonomy can be used to identify and describe what learners are doing, explain how well it is going and predict what they should do next [26]. Progression can be defined as moving up in SOLO levels, from pre-structural, to uni-structural, multi-structural, relational, and up to extended abstract level as the highest level. The first two levels refer to developing surface knowing and the latter two levels refer to developing deeper knowing. Surface learning refers to studying without much reflecting on either purpose or strategy, learning many ideas without necessarily relating them and memorising facts and procedures routinely. Deep learning refers to seeking meaning, relating and extending ideas, looking for patterns and underlying principles, checking evidence and relating it to conclusions, examining arguments cautiously and critically, and becoming actively interested in course content [27]. Each level in the SOLO taxonomy is represented by a number of verbs that can be used to formulate learning goals. For instance Multistructural is illustrated by Combine, Describe, Enumerate, Perform serial skills, list, and Extended abstract is illustrated by Reflect, Evaluate, Theorize, Hypothesize, Generalize, Predict, Create, Imagine. The SOLO taxonomy offers a hierarchical and linear structure and offers a good measure for describing progression in student competence, and is not specific to a certain subject or context.

SOLO offers a powerful model to illustrate the distinction between surface and deep in the structure of observed learning outcomes [27], it can guide in clarifying what success means [23], it can be used in assessment tools for teaching and learning [28], but most importantly, SOLO can be used to create a common language of learning in any curriculum area, and to help students of any age.
adopt a growth mindset when learning [20].

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Figure 1: Our Computational Empowerment model

3. Towards a model of CE Learning Goals

Through a theoretical grounding based in computational thinking and computational empowerment, we present an early model of progression in CE, where we seek to integrate aspects of CE with slightly wider conceptualisations regarding the development of digital technology, using the common language of learning from the SOLO taxonomy, see Figure 1. As a starting point, we look to the three aspects of CE as presented by Iversen et al. [3]. “1) engaging creatively in technology development, 2) understanding the role of digital technology in society, and 3) reflectively and critically understanding the role of technology in one’s own life.” As argued above, these overlap with the three categories of CT skills presented by Brennan and Resnick [14] “1) computational concepts, 2) computational practices 3) computational perspectives” but the emphasise different aspects. To better cover the aspects presented by Iversen et al. we propose to expand the categories by Brennan and Resnick to four: Computational Concepts, Computational Practices, Computational Perspectives in One’s Own Life, and Computational Perspectives in Society.

These categories allow for a more detailed classification of technical knowledge and skills than the original aspects of CE, as well as a finer grained un-
derstanding of the attitudes and values associated with being computationally empowered and taking a critical stance towards technology than allowed by the framework of Brennan and Resnick [14].

Having identified four categories to make distinctions between CE skills, we also need a distinction between different levels of progression in these skills. We have chosen to use the SOLO taxonomy as a common language [24], as it is a widely used tool, which provides educators with common ground for formulating learning goals that can be compared across subjects [29]. However, we acknowledge that there are other taxonomies that could be used as a common language, such as e.g. the BLOOMs taxonomy [25], and we are aware of that the SOLO taxonomy has been criticised for being simplistic and reductionist [29, 30]. Still, SOLO is a powerful tool [27], which provides an established and a common language for articulating and discussing learning goals [26], and that has been applied to many different school subjects from poetry and history [31] to science [32] and math [28], but to the best of our knowledge never before to computational empowerment. This research provides a first exploration of the use of the SOLO taxonomy in the context of CE.

By combining the four categories of CE skills and the levels of competency described in the SOLO taxonomy, we arrive at an emerging model of progression in CE, as seen in Figure 1. We propose this model as a common language for discussing and comparing CE projects, for developing and determining learning goals in new CE projects, and for establishing coherent CE research programmes.

4. Method

To answer the research question on what characterises progression in computational empowerment, we have combined related work in computational thinking, computational empowerment, and progression in learning, in order to develop an initial model, as described in the above section. In order to validate the model and investigate its applicability, we have further applied the model
in the analysis of four research projects from a larger project portfolio at our
university research centre [33]. The projects have in common that they relate
to and/or focus on computational empowerment in children and young people.

The study consists of interviews with leading researchers for each project,
while deploying the model to position and reflect upon each project. The four
projects were included in order to represent a diversity of CE perspectives. The
projects range from high school teacher training to primary school children in
special needs education. For an overview of participants, see Table I.

The project FabLab@School.dk is aimed at empowering primary school stu-
dents by engaging them in creating and imagining with technology so that they
can critically discuss their role in society. In the Computational Thinking in
Math and Science (CTiMNAT) project, high-school teachers are trained to en-
sure that their students work with a particular phenomenon related to their
subject both in itself and through code. In Computational Thinking in Hu-
manities, Arts and Social Sciences (MCTIG), a number of code based teaching
activities are co-designed with high school teachers. Finally, the Collaborative
Information Technology in special Education (CITE) project focus on children
in special education, and aims to make the children reflect on their own edu-
cational tools, and also that they can have a say in the development of digital
tools used in their education.

4.1. Data Collection and Analysis

One of the authors interviewed the leading researchers in each project. The
interviews consisted of two parts: The first part of the interview was a semi-
structured interview to understand the project activities, and to discuss the
main purpose of the project, and how it relates to CE. In the second part
of each interview, the interviewer collaborated with the respondents to fill in
the learning goals from the project in the CE model. Each interview lasted
for around one hour and took place in the respondents’ offices. Some of the
interviews were conducted in the researchers native language and translated,
some were conducted in English. All the interviews were recorded and later
For the analysis, we first analysed data from interviews for how the projects and their learning goals were positioned in relation to CE. We then mapped the learning goals of the project activities in relation to concepts, practices, perspectives in one’s own life, and perspectives in society, using the SOLO taxonomy. Two of the researchers re-categorised and synthesised some of the learning goals based on the description given in the interviews, according to the following principles: Given the hierarchy of the SOLO taxonomy, some projects had intermediate goals causally leading to a final goal, e.g., a goal of learning to download and install some software leading to learning to use the software. For such learning goals, only the high-level goal was included in the analysis. Additionally, some projects included activities rather than learning goals, such as using a particular program. These were also removed. Finally, several of the projects feature parallel learning goals in a single category of computational skills. E.g., the CTiMNAT project includes both learning the methods of a particular design model and learning to apply knowledge of design processes in different subjects as two separate learning goals within practices. Since these are seen as parallel learning goals on different levels and not as causal, they were both included in the analysis.

Having analysed the four projects individually, we reflect upon blind spots, common trends and challenges across the projects.

Finally, we articulate how the model can be used to derive general CE learning goals at all levels for a teaching activity focused on designing with technology.
5. Research Projects

In this section, we present four research projects using the emerging model presented in Section 3. For each project, we present a short project description followed by a summary of the analysis with examples of learning goals and their categorisation using the model.

5.1. #1: Fablab@School

The Fablab@School project explored the core challenges and potentials of integrating digital fabrication technologies into the context of the Danish educational system [3]. The purpose was to create a sustainable educational initiative, and to give teachers the tools to integrate design processes and digital making technologies into their teaching. It was carried out between 2013 and 2017 by a small interdisciplinary research team as a collaboration between three Danish municipalities. The project was based on the global fablab@school project developed by the Transformative Technologies Learning Lab at Stanford University. The experiment involved 1100 teachers and 11,000 students from different Danish primary schools. Fablab@school sought to empower teachers as well as students, although we for this analysis focus solely on the latter group. Regarding students, the aim was to empower them by engaging them in creating and imagining with technology in a way where its role in society could be critically examined. An overview of the CE learning goals in the project can be seen in Figure 3a.
We did not find any explicit learning goals concerning CT Concepts in the fablab@school project. In the Practices category, the fablab@school project has several learning goals. Among these were the students can carry out an iterative design process on their own case and can explain and reason about their choices in the process. Learning to conduct a process must be considered a practice, and is Relational as it requires an understanding of the correlation between design process model and children’s own designs. In the Perspectives in one’s own life category, this project has the following learning goal: Students should understand how technologies influence them in their everyday life. As it requires the students to transfer the knowledge they have gained from working with their own case to an application and consideration of the technology that they themselves encounter in their own lives, this places this goal, in the SOLO taxonomy, at the Extended abstract level. Finally, at the Perspectives in society level, the learning goal was Students should understand how the technology they created in their process could be integrated into society. As before, this fits with the Extended abstract category.

5.2. #2: Computational Thinking in Math and Science (CTiMNAT)

This is an ongoing project working with high-school math or STEM teachers. The teachers are trained to, by themselves, create teaching material in Agent Based NetLogo [34] that revolves around a particular phenomenon found in the subjects that they are teaching, and that can be used together with students. The project is based on the Coding, Modeling & Content (CMC) approach [35] which in turn ensures that the students work with the modelled phenomenon both in itself and through code. At the point of writing, 67 teachers had participated in the project. An overview of the CE learnings goals in the project, as defined for high-school students, can be seen in Figure 3b.

One of two learning goals in the Concepts category is that students should be able to understand selected parts of code. This requires the students to know certain concepts about programming and is thus categorised as concepts learning goal. Since it requires students to know certain programming concepts
and to recognise these in code, it is placed in the *Multistructural* category of the SOLO taxonomy. Another learning goal, relating to *Practices* is that students should be able to *make changes to the code that changes the model’s behaviour related to subject specific terms*. This learning goal is intended to let the students reflect on knowledge gained from the subject and from that imagine how they can create a new behaviour for the modelled based on this knowledge. This learning goal requires the students to go through a process of experimenting with the code and changing it. The goal describes that the students are able to carry out a process and therefore is considered as a practice. As it requires the students to use existing knowledge to extend the model it is categorised as *Extended abstract* in the SOLO taxonomy.

![Figure 3](image-url)
This project teaches high-school teachers from the humanities, arts, and social sciences to use NetLogo models for teaching in their subject. Through a process of co-creation with the teachers, some teaching activities based around models are created. Throughout the project, focus has been to adapt and adjust models, and model-based teaching methods to the Danish high schools. Teachers are in the Scandinavian school tradition involved in curriculum development, and co-developing alternatives for curricular activities together with the teachers is a necessary process in order to create new activities in a sustainable way, where they will be used in classrooms after the project has finished. An overview of the CE learning goals in the project as defined for high-school students, can be seen in Figure 3c.

The MCTIG project has two learning goals in the Practices category, one being: 

*Students should be able to make and justify subject-specific changes to the NetLogo code, that changes the behaviour of the model.*

After analysing and working with a model, students apply their existing knowledge about the subject (e.g., Social Studies) and based on this they alter the model. The learning goal is about a process wherein the students construct code and compare the result to subject specific theory. This is a way of working, and must be categorised as a practice. As it requires the students to both use the model and to use existing knowledge from the subject and apply this knowledge to changes of the model. Through a process of hypothesis and creation, the learning goal is categorised as *Extended abstract* in the SOLO taxonomy. In the Perspectives in society category, MCTIG has the following learning goal: 

*Students should be able to reflect on the validity of models in society and realise that they are built on assumptions.*

Students are given an agent based model by their teacher which simulates a real phenomenon. By working with these models, students should be able to understand the limitations of models and transfer these to other types of models in society such as economical models or climate models. The learning goal is categorised as *Perspectives in society*, since it requires the students to
use the perspectives from the teaching activity to reason about technology use in society. This learning goal is on the Extended abstract level in the SOLO taxonomy as it requires the students to reflect and hypothesise about new models encountered in society based on the knowledge gained through working with a specific NetLogo model.

5.4. #4: Collaborative Information Technology in Special Education (CITE)

The project worked with one class of children from special education (seven children) and the teaching personnel connected to the class. The purpose of the project was to explore and develop collaborative technologies such as e.g. games in co-design with children [36]. From a computational empowerment perspective, the aim was help the children understand that the tools they use can impact their learning, and that they can impact and modify games: Games are not only for consumption, they are also something that has been designed by other people for a purpose. An overview of the CE learnings goals in the project can be seen in Figure 3d.

The CITE project has one learning goal in the Perspectives in one’s own life category: Children should understand that they can shape technology. This learning goal describes the knowledge that the children is to have after involvement in the project activities. It is categorised as Perspectives in one’s own life, since it describes how the activities should shape the children’s understanding of themselves and technology. It is classified as Relational as it describes the children’s relation to technology in their own life, and in order to actually have achieved this learning goal the children would have to understand different processes in game development and relate them to each other and their own abilities to influence game design and affect the design of a game. In the Perspectives in society category, CITE has the following learning goal: Children should understand that technology is not necessarily complete, but follows an iterative process. The goal is about shaping children’s view of what technology is, and how it affects society, which places the goals in the Perspectives in society category. This learning goal is Relational since it is about relating the process
children have taken part in during the experiment with technology encountered elsewhere in society.

Together, these four projects give an indication of how current CE projects relate to the broad goals of CE. We can see that a single project rarely encompasses all aspects of CE, and looking at the heatmap of all projects in Figure 4, we see that learning goals seem to gravitate towards more advanced levels of the SOLO taxonomy. While it is understandable that research projects aim to qualify their work in regards to high levels of competencies in their participants, we argue, that it might be difficult for a teacher to know how to structure intermediate learning goals in their own teaching based on these projects. Below, we discuss what to consider when striving to computationally empower students, and we provide an example of how the model can support teachers and researchers in defining subject specific learning goals for computational empowerment.

6. Discussion

In this paper, we have provided the first steps towards a model of progression in Computational Empowerment (CE) in education. The model is developed
by combining aspects of computational thinking with computational empowerment, using the structured of the SOLO taxonomy. To qualify the model, we have analysed four research projects with a focus on educational activities and learning goals connected to CE. Based on this analysis, we will here discuss the strengths and weaknesses of the model, and address the research question: what characterises progression in computational empowerment in education?

Dindler et al. state that computational empowered is when “people are empowered to autonomously and critically engage in the development of digital artefacts” [5]. Although we do not disagree with this, we think that there is a lack in what characterises progression in CE in order to be able to teach and assess it.

By combining attitudes and values with knowledge and skills in line with OECD [20], we argue that in order to be computational empowered, you need to reach the relational and extended abstract levels as in the SOLO taxonomy [24] in concepts, practice, perspectives in one’s own life and perspectives in society. When teaching for computational empowerment, you need to support the learners in both knowing and doing, as well as in becoming [21] [22]. This approach acknowledges that principles and beliefs influence one’s choices, judgements, behaviours and actions in regards to the individual, society and environment, and is vital for an autonomous critical reflective engagement in the development of digital artefacts.

As presented earlier, a learning progression is a sequence of subskills that needs to be mastered to reach a curricular aim [16], and is characterised by starting with something simple and moving on to something more advanced, applying the knowledge in new ways. However, in computational empowerment, we do not yet have a model of best practice for how to guide teachers in what to expect from learners at different levels of skill, and how they can make progress.

Analysing the results from Figure 4, we can see that CE relies heavily on practices, and that CE focuses more on the higher levels of the SOLO taxonomy: multi-structural, relational and extended abstract levels [24]. This goes in line with that critical thinking is a major driver within CE [5], as critical
Uni-structural  Multi-structural  Relational  Extended abstract

**Concepts**

Students will be able to **recognise and identify** generative concepts, tools, methods, and materials for designing with technology.

Students will be able to **list and describe** generative concepts, tools, methods, and materials for designing with technology.

Students will be able to **compare and contrast** different generative concepts, tools, methods, and materials for designing with technology.

Students will be able to **create** new technological artefacts using generative concepts, tools, methods, and materials for designing with technology.

**Practices**

Students will be able to **recognise and identify** procedures for designing with technology.

Students will be able to **perform serial activities** for designing with technology using generative tools, methods, and materials.

Students will be able to **integrate or analyze** several procedures for designing with technology.

Students will be able to **create** new generative tools, methods, and materials for designing with technology.

**Persp./Own Life**

Students will be able to **recognise** that different tools, methods and materials for designing with technology can have substantial impact on their lives.

Students will be able to **list and describe** possible impacts on one’s own life of different tools, methods and materials for designing with technology.

Students will be able to **relate to** different tools, methods and materials for designing with technology.

Students will be able to **critically reflect** on personal trade-offs between different tools, methods and materials for designing with technology.

**Persp./Society**

Students will be able to **recognise** that different tools, methods and materials for designing with technology can have substantial societal impact.

Students will be able to **list and describe** possible societal impact of different tools, methods and materials for designing with technology on a societal level.

Students will be able to **relate to** societal impact of different tools, methods and materials for designing with technology.

Students will be able to **critically reflect** on societal impact of different tools, methods and materials for designing with technology.

Table 2: Examples of learning goals in computational empowerment with a focus on designing with technology. Persp/Life is short for Perspectives in one’s own life, and Persp/Society is short for Perspectives in society

thinking is an extended abstract competence. To further inspire teachers and researchers, when defining their subject and learner specific CE learning goals,
we suggest examples of learning goals for all competency levels of computational empowerment, here specifically targeting designing with technology, see Table 2. The suggested examples of learning goals were formulated by mapping verbs from each level in the SOLO taxonomy, to concepts, practices and perspectives deriving from CE and CT, and serve as an illustration of how the model could be applied in practice.

It should be noted that these learning goals in designing with technology do not cover all aspects of CE, but rather serve as an example to illustrate and articulate progression in accordance with the model. In order to teach CE, these learning goals need to be complemented with other learning goals, such as e.g. envisioning the consequences of a technology, understanding indirect and direct stakeholders of a technology, identify and evaluate the implicit and explicit values of a technology, reflect on the role of the designer, etc.

6.1. Limitations of the Model

The model has several limitations, that should be addressed in order to move towards a deeper understanding of progression in CE. First, we found the vertical axis to be useful. It allowed us to classify the learning goals of the research projects in meaningful ways, that could be compared both within and between projects. We did, however, have some issues using the horizontal axis. The SOLO taxonomy implies that learning goals and thus learning can be divided into four categories, which arguably is a reductionist view on learning [30]. We witnessed this in the interviews, where it was sometimes difficult to agree on the categories of different learning goals. There are however, also arguments for using the SOLO Taxonomy; it is already widely used in education and is a familiar tool for teachers [29]. Further, its simplicity allows learning goals to be formulated precisely and in ways that make them comparable between projects and classes. Secondly, we only included projects, for which we had access to researchers with first-hand experience, similarly to the approach taken in [37]. We considered including experiments from other researchers. However, from our interviews, we found that CE learning goals for an activity is often
implicit and therefore requires first-hand access to data and researchers involved in the experiment. We do however suggest, that other researchers interested in empowering youth and children apply the model to their own projects.

We further acknowledge the importance of social aspects of learning, and the need for differentiating by taking each individual’s needs, interests, and goals into consideration, and the individual child’s ability for regulation of cognition, socio-emotional factors and behaviour. However although such aspects are not currently part of the suggested model, we highly encourage the teachers and researchers to consider such aspects when adopting the model in their own subject and learner specific contexts.

Finally, we acknowledge that there is still no common clear-cut understanding of what the E in CE mean. However, the proposed model can be seen as a first step towards understanding progression in computational empowerment in education, and hopefully make a contribution to the existing body of literature.

6.2. Future Work

In the previous sections we have demonstrated the model’s ability to analyse projects and shed light on the coherence of research programmes. We see several directions in which the model could enhance our understanding of CE in education. The generative abilities and its usefulness to help teachers determine CE learning goals for their teaching should be explored. Similarly, the model is a first step towards a tool for researchers to look beyond CE learning goals of specific projects and begin to form coherent portfolios of research projects with different focus points. Finally, work is needed that go beyond learning goals and look toward evaluating computational empowerment in children. We see the model as a first step towards formulating learning goals for CE that lend themselves to being evaluated and assessed.

7. Conclusion

In this paper, we have addressed the research question on what characterises progression in computational empowerment. The contribution is an ini-
tial model of progression in computational empowerment in education. The model has been developed by merging aims from computational thinking with computational empowerment, and the progression has been structured using the SOLO taxonomy. The model has been applied in the analysis of four different research projects. To illustrate how the model can be used to formulate learning goals, examples of learning goals for designing with technology have been suggested. It is the hope of the authors that this initial model of progression in computational empowerment, as illustrated by examples of learning goals, can serve as a guide to on the one hand teachers in what to expect from learners at different levels of competency, and on the other hand support researchers when defining projects and research questions. Looking forward, we invite other researchers and practitioners to critique, revise and discuss the model.

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