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Integrating CT into Biology: Using Decision Tree Models to Classify Cell Types

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ABSTRACT
The integration of computational thinking (CT) into subject learning has the potential not only to foster digital literacy, but also to deepen STEM learning because the use of computational models and development of computational solutions advances students' understanding of subject area content. However, designing and implementing a curriculum that effectively integrates STEM and CT is challenging for educators because they have little experience in computing terminology, key concepts, and approaches to learning. We therefore aimed to develop CT integrated K-12 lessons in collaboration with subject teachers to determine suitable CT learning objectives as well as teaching and learning strategies. In this study, we focus on a 9th-grade biology lesson where students were asked to construct decision trees for determining cell types in as few steps as possible. Decision trees form a computational model that fits a wide range of classification systems in biology. We investigated the effect of using decision trees on students' biology and CT learning outcomes by analyzing their end products in the assignment. Additionally, we analyzed students' and teachers' views about the CT integrated lesson using questionnaires and semi-structured interviews. We found that students valued the way a decision tree helps them to structure the information. The teacher expressed that drawing a decision tree enabled the students to reason about the cell types, fostering a different way of thinking. Regarding CT, decision trees may help to improve decision analysis and classification, which are related to abstraction and algorithmic thinking skills.

KEYWORDS
Computational thinking, STEM, biology, K-12, decision tree.

1. INTRODUCTION

1.1. CT Integration into STEM Disciplines

In an effort to deepen learning in K-12 Science, Technology, Engineering, and Mathematics (STEM) fields, there is an increasing interest to integrate computational thinking (CT) into subject learning. Computational approaches are vital for STEM practices because how these disciplines are practiced in the professional world is rapidly changing (Foster, 2006). In recent years, STEM fields have been supported with computational practices, for example in Bioinformatics, Computational Statistics, Chemometrics and Neuroinformatics (Weintrop et al., 2016). Bringing computational tools and practices into K-12 mathematics and science classrooms gives learners a more realistic view of what these fields are, and better prepares students for professional careers in these disciplines (Augustine, 2005). This sense of authenticity and real-world applicability is important in the effort to motivate diverse and meaningful participation in computational and scientific activities (Blikstein, 2013; Weintrop et al., 2016).

There are many research studies about new learning environments, tools and activities designed to promote computational thinking skills in different science contexts. In these studies, several science topics in K-12 are presented in which CT may be embedded. For example: simple electronic circuit, circuit diagram (Jacobson et al., 2015; Kafai et al., 2014), digital and analog waves, wave amplitude and frequency, modern sonography (Lehmkuhl-Dakhwe, 2018); kinematics (Basu et al., 2015); geology, meteorology, astronomy, and energy (Peel et al., 2015). There are also efforts to include different media and tools in science such as programming environments such as Scratch (Resnick et al., 2009) and Alice (Lee et al., 2011); computational modeling environments such as NetLogo (Wilensky and Rand, 2015); electronic prototyping kits such as Arduino and digital textiles (Buechley et al., 2008); video games including Quest Atlantis (Barab et al., 2005) and RoboBuilder (Weintrop & Wilensky, 2013).
Many investigations focused on the impact of programming skills or computational media towards learning computational thinking (CT). However, not all teachers are able to implement or teach a programming curriculum at the K-12 level. In this sense, another notable approach to bringing computational thinking into K-12 classrooms is the use of unplugged activities (i.e., in which there is no use of digital devices). In this study, we investigated the use of decision trees as an unplugged approach to enhance biology and computational thinking skills of 9th grade students.

1.2. Decision Tree Models' Relation with CT

A decision tree is a decision support tool that uses a flowchart-like model/diagram of decisions and their possible consequences to help identify a strategy most likely to reach a goal. It is one way to display an algorithm that only contains (possibly nested) conditional control statements (if-then-else). The structure of a decision tree is built on three main parts: a root node, decision nodes (or branches) and leaf nodes (Figure 1).

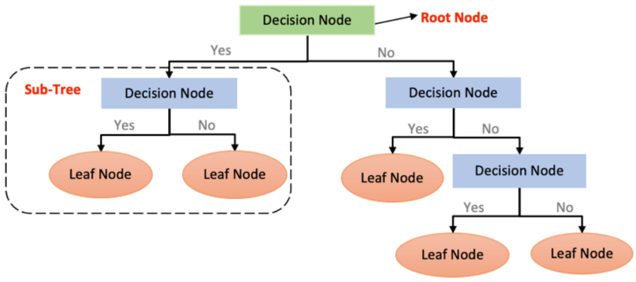

Figure 1. Decision tree structure

The root node is the starting point of the tree, and both root and decision nodes contain questions or criteria to be answered. Branches are arrows connecting nodes, showing the flow from question to answer. Each node typically has two or more nodes extending from it. For example, if the question in the first node requires a "yes" or "no" answer, there will be one node for a "yes" response, and another node for "no." Leaf nodes represent the classifications. Decision trees are commonly used in decision analysis and classification; they are also a useful tool in machine learning (Othman et al., 2018).

A decision tree model may help to improve CT skills because it is a model that fits a wide range of classification systems in biology. By using or drawing a decision tree, students can visualize the relationship between the characteristics of a subject related phenomenon. Designing simple algorithms in the form of decision trees could assist in the strengthening of algorithmic thinking skills and can show that there are different algorithms to reach the solution. Furthermore, students are supposed to separate important from redundant data while creating their decision nodes which may contribute to enhance students' abstraction skills. While designing decision trees, students are supposed to divide a larger and more complex task (root node) into several sub-tasks (decision nodes) which is related to students' decomposition skills. It also seems a helpful tool for improving evaluation skills of students, because they can evaluate the decision trees according to predefined criteria and they can see the quality of their solutions and make improvements. For teachers, it can be used as a formative assessment tool because students' understanding and misconceptions can be easily noticed in decision trees and the evaluation of a decision tree can be automated (Petrović & Pale, 2017).

1.3. Decision Tree Applications in Biology

Bioinformatics is a growing scientific field created by the intersection of biology, computer science, and information technology to support the storage, organization, and retrieval of biological data (Wheeler et al., 2006). It is important to know how to support secondary school students to engage with real-world science developments using scientific and computational techniques, such as decision trees. Decision tree approaches have been shown to have wide applications with high performance in solving bioinformatics problems. For example, there have been several attempts to use decision trees for the classification analysis of the gene expression data (Dudoit & Fridlyand, 2002). Specifically, decision tree approaches have been widely applied in cancer classification and in annotating multilevel genomic sequences (Che et al., 2011; Salzberg et al., 1998). Bioinformatics can therefore be used as a context to introduce students to real-world environmental datasets and to support students in developing their CT skills.

The real-world applicability of decision trees is important for motivating teachers' and students' participation in computational and scientific activities. Another motivation for this research study is that there is little guidance and support for science teachers to integrate CT with existing content (Grover & Pea, 2013; Weintrop et al., 2016). For this reason, the aim of this study is to develop a CT integrated biology lesson plan together with a science teacher and to investigate the effect of this lesson and the decision tree applications on 9th grade students' biology and CT skills while learning about cell types. Also, we aim to explore the students' and teacher's attitudes towards a CT integrated lesson and their views about the lesson. Consequently, this study addresses the following research questions: 1) What are the biology and CT related learning outcomes of a CT integrated lesson? 2) What are the students' and teacher's attitudes towards a CT integrated lesson?

2. METHODOLOGY

This study is part of a larger project (Barendsen, 2022) focusing on the definition of learning trajectories for CT integration into the K-12 curriculum. In particular, this study focused on investigating the effectiveness of a CT integrated biology lesson. To this end, we employed a qualitative case study approach (Stake, 1994) to explore the effectiveness of a CT integrated lesson (specifically decision trees) on high school students' biology and CT skills while learning about cell types. Patton (2002) defined cases as a "specific, unique, bounded system… [in which researchers] gather comprehensive, systematic, and in-depth information" (p. 447). Within this approach, the CT integrated biology lesson is our specific unit of interest. The following (sub-)sections describe the research design, participants, data collection, and data analysis process.

2.1. Lesson Design

This case study was implemented in a secondary school in the Netherlands. The participating teacher attended a workshop where he was shown CT concepts and examples of lessons in which CT was integrated into several disciplines across the curriculum, such as science, humanities, and languages. Then, the teacher worked with the researchers individually and developed a lesson plan about a biology topic he planned to teach anyway, as well as with the level and type of CT he felt comfortable with. In this biology lesson, students learn about the cell types. Learning objectives of the lesson are presented in Table 1.

Table 1. Learning Objectives (LO)

Subject-related LO	Computational Thinking-related LO
Identify different types of cells	Use diagrams to represent data at an abstract level (AB)
Describe the characteristics of each type of cell	Separate the important from the redundant information (AB)
Use the cell type knowledge to create a decision tree	Design simple algorithms such as if statements for decisions (AT)
	Recognize that different algorithms exist for the same problem (AT)
	Use criteria to evaluate the quality of solutions and identify improvements (EV)
	Check whether no important part is missing or forgotten when performing partial assignments (EV)

AB: Abstraction, AT: Algorithmic Thinking, EV: Evaluation

There are three different instructional strategies applied in this lesson plan: direct instruction, scaffolding, and collaborative learning. At the beginning of the lesson, the teacher used direct instruction to summarize the topic of cells and kingdoms and the types of cells. They had already discussed this topic in the previous lesson. At the start of the lesson, students were sitting in a circle and it allowed everyone to see each other and helped to promote engagement. Then the teacher shared the printouts with the assignments. The teacher explained that students were going to construct a decision tree to determine the types of cells (bacteria, fungi, plants, and animals) in as few steps as possible. He described decision trees and the way students could draw them. Students were encouraged to ask their questions. They moved to their desks in groups and drew their decision trees on paper individually. Scaffolding was implemented by the teacher to give support to students whenever needed. As a part of collaborative learning, students had their decision tree checked by a classmate. They evaluated their classmate's decision tree according to predefined criteria (content, classification, and presentation/visualization). Then, they used the feedback obtained to create a second version of their decision tree.

2.2. Participants

In total, 22 9th grade students were involved in this study. For 18 students, we received signed consent forms. The age range of students is between 13 and 16, with an average of 14. The participants were nine girls and eight boys; one participant reported the gender as other. All students (except one student) have either a computer, a tablet, or a smartphone available if they need them. They were also asked about their programming experience. Prior activities in school that focused on CT were related to programming. Six students have never taken a programming lesson. 10 students have had a programming lesson, however six of them have had lessons for less than one month and three of these 10 students have had programming lessons less than one year. Only one student has had programming lessons for 2-3 years. The most used programming language is Scratch, which was reported by five students. They were also asked to rate their programming experience between one (no experience) and five (very experienced). Half of the students (nine) rated themselves as one or two, five students rated as three and only two students rated themselves as four or five. 12 students reported that they need help during programming. In previous biology lessons, students have worked with models that resemble decision trees, for example classification charts. The biology teacher is 34 years old, male, and has 14 years of teaching experience. He is a project leader at digital literacy projects and attended this research voluntarily. He has no prior programming experience.

2.3. Data Collection and Analysis

The data were gathered using a short survey, an exit ticket, an artifact/end product (decision tree) and interviews with a few students and the teacher. The short survey included questions on age, gender, grade, programming experience and self-efficacy. The exit ticket was completed at the end of the lesson, to understand students' attitude toward a CT integrated biology lesson. It includes questions about various topics (enjoyment, interest, clarity, comprehension, difficulty) with a three-point Likert scale and eight open-ended questions about attitudes toward lessons, likes/dislikes etc. Students' decision trees and their classmates' feedback were collected. Additionally, four students were interviewed and were asked to elaborate on some of the questions from the questionnaire. Following the lesson, an interview with the biology teacher was conducted. The interview followed a semi-structured interview protocol that included questions regarding learning goals, instructional strategies, students' understanding, and assessment and questions to capture the teacher's attitude towards the CT integrated biology lesson. The interviews were audio recorded and transcribed verbatim. The analysis procedure started with an evaluation of the correctness and efficiency of the decision trees to investigate students' learning outcomes regarding cell types. The decision trees, surveys, exit tickets, and students' interviews were used for the analysis of students' learning outcomes regarding CT and students' attitude towards the CT integrated biology lesson. The analysis aimed at capturing students' experiences and the variation in students' ideas. The interview data were analyzed inductively. When analyzing the teacher's attitude and views, four categories were discovered.

3. RESULTS

In this section, we first report the results regarding the effect of using decision trees on students' biology and CT learning outcomes. Furthermore, the results of the analysis of students' and teacher's views about the CT integrated lesson are reported. The students' quotes were translated from Dutch into English. This also applies to the translated text in the decision trees except for 'ja' (yes) and 'nee' (no) (Figures 2-5).

3.1. Biology Learning Outcomes

Students had drawn decision trees to classify cell types and these drawings were used to analyze students' biology learning outcomes. A correct decision tree with as few questions as possible should include three questions about cell nucleus, cell wall, and chloroplasts. 13 out of 18 students made a decision tree with three questions. Questions could be asked in different order, for example in Figure 2 the first question is about chloroplasts while in Figure 3 the first question is about the cell wall. Seven out of these 13 students did not use correct questions, for instance, they asked whether there was a vacuole or cytoplasm, which are no distinctive characteristics of cells.

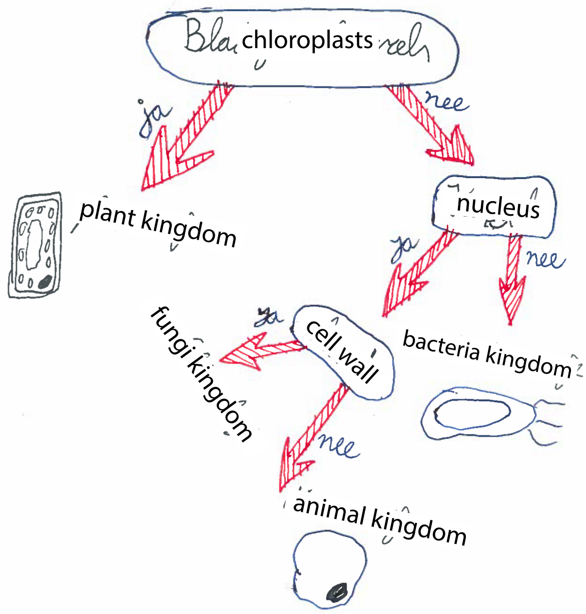

Figure 2. Example of correct decision tree (Student [S]16)

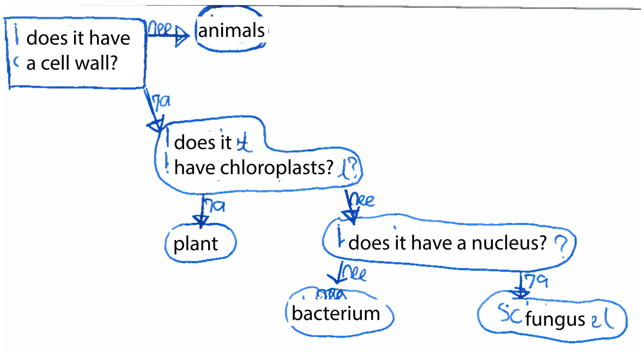

Figure 3. Example of correct decision tree with questions in different order (S10)

Furthermore, five out of 18 students constructed a decision tree with four or five questions. This reveals that it is not obvious for students to design suitable questions for determining cells. In addition, it shows that asking students to draw a decision tree may be a helpful instrument for formative assessment because misconceptions about distinctive characteristics are easily visible.

3.2. CT Learning Outcomes

The analysis of students' decision trees, completed surveys and exit tickets, and the interview transcripts revealed students' learning outcomes regarding CT, especially regarding algorithmic thinking, abstraction, and evaluation.

Algorithmic thinking. All students were able to design a simple conditional algorithm in the shape of a decision tree. Because the questions could be asked in different order, different algorithms could be designed. In the interviews with students, we explicitly asked whether they realized that multiple decision trees could be correct. But a question about differences between student's own decision tree and the decision tree of peers was interpreted by a student as difference in appearance: *"she used circles and I had drawn text and arrows"* (Student [S]15). Other students realized that several solutions are possible but did not really know how to explain why there are more options. When asked why then they would choose one or the other, one student replied: *"maybe because you're more used to it or it's easier"* (S2).

Abstraction. All students were able to use a decision tree to represent data at this abstract level. Another learning goal for abstraction was to separate important from redundant information. The decision tree could be made with three questions; however, some students did not omit unnecessary details. This is clear in the decision tree in Figure 4, where the last question is redundant.

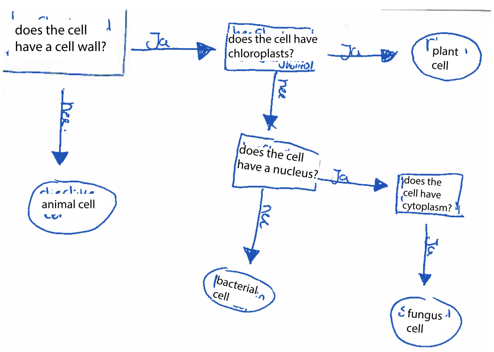

Figure 4. Decision tree with redundant question (S5)

Evaluation. Students were supposed to ask each other for feedback. Most of the given feedback is either a compliment ("*well and clearly made*") or is about the appearance of the drawing "*make it neater*". Some students then drew a new version. Figure 4 is such an improved version, the first version made by this student is shown in Figure 5. It is interesting to note that the questions are the same as in the first version (which means too many questions), but in Figure 4, rectangles are used for questions and ovals for the four kingdoms, which makes the structure/the algorithm much clearer.

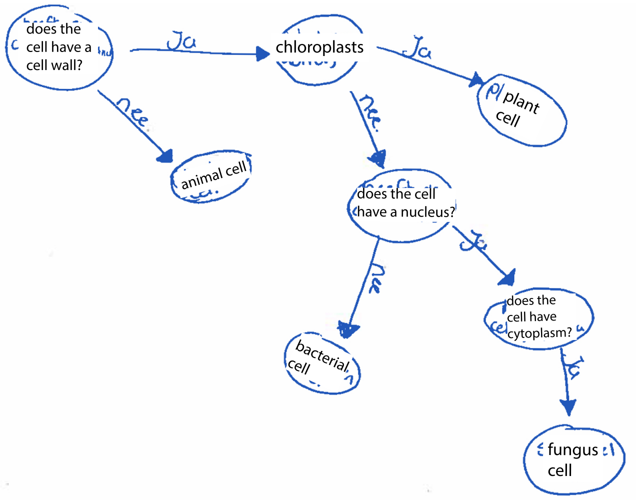

Figure 5. First version of decision tree (also made by S5)

3.3. Students' Attitude toward CT Integrated Biology Lesson

The analysis of the exit tickets completed by the students revealed that most students (16 out of 18) understood the lesson. 13 students reported that they understood the assignment. Ten students answered that the lesson was not difficult. Students were divided on the question whether they enjoyed the lesson (seven students enjoyed the lesson, seven students were not sure and four did not enjoy the lesson). More than half of the students (10 out of 18) found the lesson interesting, six students were not sure and two did not find it interesting.

The analysis of the questionnaires showed that most students were satisfied with their decision tree, either because "*it was clear*" (S6) or "*it was right*" (S13) and one student also described "*because I understand it better*" (S3). Students valued the way a decision tree helps with the determination of cells because *"it helps you get an overview"* (S16) or "*because you ask yourself questions and you answer them too*" (S10). During the interviews, one of the students commented that a decision tree helps because *"then you can look it up somewhere, because in your head you are already doing that"* (S15). And another student reported that a decision tree is helpful for the determination of cells because *"if you know the characteristics, it is easy to use; for example, when you know that there is no nucleus, then you can distract it* [the kingdom] *easily"* (S9).

In the questionnaire, students were asked if they could give examples where computers could use decision trees. A student answered that a decision tree might help for learning about animals (instead of cells) and another student replied that it might be useful *"for finding the right information"* (S7).

3.4. Teacher's Attitude and Views toward CT Integrated Biology Lesson

Results of the teacher's attitude and views are presented according to the categories that emerged from the inductive analysis.

Learning goals: The teacher's main goal for the students was to learn about cells and their characteristics and to be able to distinguish the four kingdoms. According to the teacher, the integration of CT in the lesson was supportive of this biology learning. Last year, the students had used a decision tree or search map, but this time, students were asked to draw the decision tree themselves. Structuring the information was hard for students but it contributed to their learning about cell types.

Way of learning: The teacher described that by asking students to draw a decision tree, they learn a different way of thinking: "*they had to reason it in a certain way, rather than memorizing it or making a guess; and I think I addressed that* [the reasoning]". According to the teacher, this reasoning is especially relevant for learning biology because there are many topics that you can either memorize or reason logically, for instance regarding blood types. "*Biology is nothing but logical reasoning, if this… then that…then this… And this is a very nice way to deal with that, specifically for students of this level of education.*"

Assessment: The teacher noticed that asking the students to draw a decision tree gave him a better insight in the students' understanding. When he previously covered this lesson topic, he would use interactive instruction and only get an idea of the understanding of the three students that would participate in the conversation. This lesson, however, will provide him with an understanding of all students and "*much more of their way of thinking*". Therefore, the decision trees did not only support students in their learning, but also provided the teacher with an improved awareness of students' understanding.

CT integration: The teacher appeared to have a positive opinion of the integration of CT in the biology lesson: "*the integration, that's just very important to me*". He valued the integration because the learning of CT helped students learn biology. During the interview, the teacher also commented on the way CT was integrated in the biology lesson. In the lesson, students used pen and paper to draw a decision tree, which was fine according to the teacher because "*learning CT doesn't always have to be digital*".

4. CONCLUSION AND DISCUSSION

In this study, we aimed to explore students' learning outcomes about biology and CT, as well as students' and teacher's attitudes towards the CT integrated biology lesson. Regarding the biology learning outcomes, the results reveal that all students struggled to design good questions for classifying the different types of cells. Some students have difficulty to understand the distinctive characteristics of different cell types. Among the many different approaches to teach biology to secondary school students, decision trees seem a useful tool for teachers to help students to structure their knowledge instead of memorizing the knowledge. While creating decision trees by using the biology knowledge, students are exposed to high-level thinking activities (such as analysis, synthesis, evaluation) (Bloom, 1956). Additionally, in this lesson, the teacher encouraged students to create their own decision tree via less-structured scaffolding. However, depending on the teaching approach of the teacher, the complexity of the subject, or the development level of students, more guided/structured scaffolding can be offered during the design stage of the decision tree to avoid misconceptions and mistakes.

Regarding CT learning outcomes, the results show that students were able to design simple algorithms by using if-statements, which improves the algorithmic thinking skills of students. Some students made a clear visualization, which helps to improve abstraction skills of students. Some students could not separate redundant from important information and added some unnecessary questions in their decision trees which is related to their abstraction skill. Related to the visualization aspect of decision tree models, it is a well-known fact that the ability to effectively use visualizations is an important aspect of computational thinking, particularly as it relates to the STEM fields (NRC, 2011). In addition, the ability to create, refine, and use models of phenomena is a central practice for scientists and mathematicians (NGSS Lead States, 2013). The process of designing a model involves making methodological and conceptual decisions and there are many reasons that might motivate designing a model, including wanting to better understand a phenomenon, to test out a hypothesis, or to communicate an idea or principle to others in a dynamic, interactive way (Weintrop et al., 2016). The results also revealed that students' evaluation skills could be improved. Their evaluations and feedback were mostly related to the visual design and were much less related to biology content or algorithms.

Overall, the general attitude of students toward the CT integrated biology lesson was positive and they found it interesting. Students valued the way a decision tree helps with the determination of cells. Also, the teacher's views about the lesson are quite positive and he described that a decision tree helps to teach reasoning which is a very useful skill for biology lessons. It also offers a way of formative assessment and provides the teacher with an improved awareness of students' understanding. An unplugged decision tree is easy to use for teachers and students. The use of decision trees shows that is not necessary to have full programming or IT knowledge to be able to integrate CT into a disciplinary context.

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