Bachelor's Thesis Computing Science


Radboud University Nijmegen

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**Exploring sustainability in the computing science bachelor's at Radboud University**

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**Abstract**

Sustainability is a growing topic in computing science education. Therefore it is important to understand how to teach sustainability in a computing science context. Previous research has explored curriculum-wide or course-specific solutions but not on the inter-course level. This paper explores teachers' views and opinions on teaching sustainability in the CS bachelor's programme at Radboud University through semi-structured interviews. These teachers' input resulted in the conclusion that sustainability aspects are deemed important and valuable to include but are currently not included. To best support teachers in implementing sustainability aspects they need support in various ways: Proper tools for energy usage monitoring, a more coordinated approach among teachers and to grow their awareness of how sustainability is relevant to the programme. Finally, 3 approaches to implementing sustainability were identified. Namely, a separate course on sustainability, a full integration throughout the bachelor's or both of these approaches combined.

# Contents

# Chapter 1

# Introduction

Almost every part of our life has been changed by computing science: communicating, living together and working. There are, however, also some downsides to the ubiquitous use of computing science in terms of sustainability.

Sustainability is most commonly defined as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*[9][8].

For example, the electronic devices we use create massive amounts of e-waste. E-waste is a generic term for electric and electronic equipment that is no longer of value to their owner [13]. A report from 2017 estimates that the world created 44.7 million metric tonnes of e-waste in 2016. Enough e-waste to create 4.500 Eiffel towers of e-waste every year [1]. This is projected to increase as the life cycle of electronics gets shorter and more people own multiple devices.

Then there is the problem of energy usage. Not just the devices that people use, but also the devices in the back end that draw enormous amounts of power. Data centers drew 3% of power globally in 2017, and this is expected to rise to 4,5% in 2025. This makes data centers the largest user of energy consumption worldwide [7].

More generally, in the most recent Intergovernmental Panel on Climate Change (IPCC) report, it is stated that we are already witnessing the severe impacts of climate change and that the IPCC is even more convinced than previous reports that it is human induced [6]. Major reductions in greenhouse gas (GHG) emissions can still lead to a 1.5 degree warming pathway but this requires more effort than is currently being put into the problem. It is estimated that 2.1-3.9% of global GHG emissions have been caused by ICT, with increases in efficiency going hand in hand with increased emissions.[4]

This is not an exhaustive view of sustainability topics, shown together in figure1.1, but they are challenges where computing science can play a role

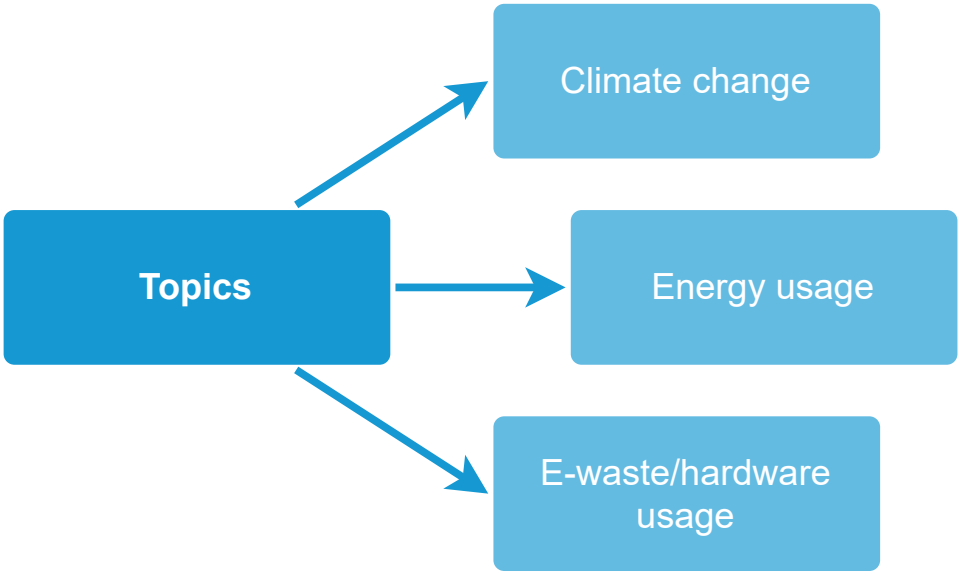


Figure 1.1: Sustainability topics laid out in this introduction

in creating a more sustainable world. Computing science education plays an important role in raising awareness among aspiring computing scientists. The United Nations Educational, Scientific and Cultural Organization (UNESCO) has adopted a future minded approach that humanity should be educated on a wide range of environmental, social and economic issues to tackle the future [11]. The Radboud University has started a project on concretely implementing sustainability aspects to help achieve the goals UNESCO has set out [12].

Within the computing science (CS) department at Radboud University this thesis aims to support this broader goal.

This paper looks at how teachers are currently implementing sustainability into computing science education at Radboud University and how they can tackle this in the future. Concretely, this thesis aims to answer the question: *What are teachers' stances on sustainability in the CS bachelor's at Radboud University and how can sustainability be incorporated in the future?* This is done by conducting interviews with teachers. Their opinions and insights into the current situation of sustainability in CS and how they see sustainability in CS developing in the future are used to construct advice for the CS bachelor's at Radboud University.

# Chapter 2

# Related Work

Research into how education can play a practical role in teaching up and coming computer scientists how to consider sustainability in CS is limited. There is, however, a lot of theoretical research into this area. There is research on how sustainability in CS can be taught. This research can be broadly divided into two categories. The first category focuses on sustainability in CS as a field or curriculum, often remaining abstract. The second category focuses on one course or projects and how sustainability can play a practical role in transforming such courses or projects. There are also several perspectives on how sustainability within computing science should be tackled, an incremental, enabler, or disruptive perspective. These perspectives are important to take into account as different teachers' perspectives can change the advice coming out of this research.

## 2.1 Sustainability in computing science education

The first category has several philosophies. Easterbrook argues for a change from 'computational thinking' to 'systems thinking' [3]. In his research, Easterbrook defines the tendency of other researchers to subdivide the world into a series of problems that have a series of computational solutions (computational thinking). In reality, to be sustainable means to acknowledge that the three themes technology, human behaviour and environmental impacts are intertwined, and they require thinking of it as one connected system to develop sustainable computing solutions: systems thinking. Peter Charles Taylor argues for 'transformative science education'[10]. He argues that this means equipping students with the skills and knowledge to tackle the problems of the future. He argues that students need this to deal with the interaction of environmental, sociocultural and economic issues. There is significant overlap here between the previous three themes mentioned by Easterbrook. Taylor further emphasizes the active role that teachers can

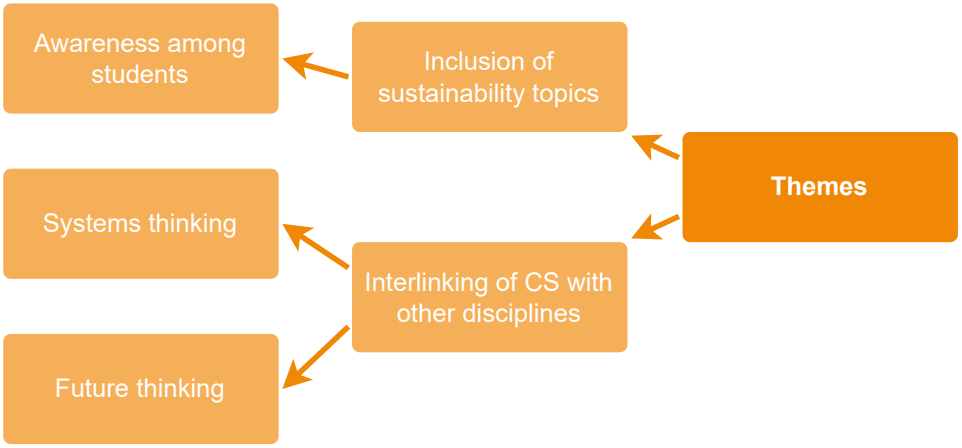


Figure 2.1: Literary themes that are important for implementing sustainability in a CS bachelor's

play in enabling students to develop these skills.

In general, this first category teaches us that we should take into consideration that computing science is more than just linear problem solving. Students need to be prepared for a world where many disciplines are intertwined.

The second category is research that takes one course or a project inside a course and transforms it according to sustainability principles. A notable example for a high school computing science course showcases that students improved in understanding green computing concepts and were more enthusiastic about sustainability afterwards. It was, however, difficult to judge whether a single course also impacted the students' future decisions[2]. Another study also noted a clear increase in students' awareness for sustainability after they followed a module covering sustainability in computing science[5]. This teaches us that we should take into consideration that the mere inclusion of projects and assignments that cover sustainability topics already motivate and teach students to care about sustainability in computing science.

This makes it clear that sustainability can and is being included in computing science and that it can be done curriculum wide or one project at a time[2][5]. There is a gap between the two categories, on the inter-course level. The impact that a module has on a student's future decisions and on how a teacher can manifest a change in students' future behavior on the topic of sustainability in computing science still has to be researched.

## 2.2 Perspectives on sustainability in computing science

There are three notable perspectives on sustainability in computing science: incremental, enabler and disruptive [9]. The incremental perspective can be seen as that we can adjust existing software and hardware to reduce their environmental footprint. This perspective is lighter than the other two, believing that our current routines and ways of working only can still be changed or updated to deal with sustainability in computing science. A teacher can, for example, update an existing course to include a different lecture focused on a certain sustainability aspect.

The enabler perspective takes IT as the main way to tackle sustainability issues, requiring new developments to bring a more sustainable future. Taking this perspective means computing science has a bigger role in the context of sustainability. To tackle sustainability issues we would need to develop new tools and hardware that do not exist yet. Through this perspective CS can also be a way to solve sustainability problems that are not caused by CS itself. A teacher could, for example, introduce novel tools in their courses or start a new course focused completely on sustainability in CS.

The disruptive perspective sees the major sustainability issues that we face requiring structural societal change. This can been seen in the attempt to switch to 'systems thinking' as explained by Easterbrook in section 2.1, a novel way of tackling computing and sustainability problems. For teachers, this could involve changing a whole curriculum to adhere to this new philosophy.

# Chapter 3

# Method

## 3.1 Participants

### Context

The research has been done at Radboud University, more specifically within the building that houses the computing science department. Interviews were held in the offices of participants themselves, with only the participant and the researcher present.

### Sampling strategy

The sampling of participants was done through convenience sampling. The available participants, by nature of the research question, were limited to teachers employed by the institute for Computing and Information Science (iCIS) who also taught a course in the bachelor's. The researcher divided the possible participants in the three major subdepartments (Software Science, Data Science and Digital Security) and ensured equal representation of each. This division was chosen as every subdepartment was assumed by the researcher to have a different view on what sustainability aspects are important to computing science. This assumption was based on his own experience studying the bachelor. As this is an exploratory study, the sample was not aimed at being a complete view of the entire computing science department, but rather a clear view of possible differing opinions and views on the subject of teaching sustainability in computing science. For both reasons of time and availability of teachers a sample of nine was decided on, three per sub department. The supervisors, prof. dr. Erik Barendsen and dr. Bernard E. van Gastel were not sampled for the research but their feedback was incorporated into the interview guide (see section 3.2). The participants were approached on a face-to-face basis. If they responded positively they then received further e-mail correspondence.

### Units of study

Nine participants were approached initially, one participant declined to participate on the basis of not wanting to be voice-recorded. A $10^{th}$ participant, from the same sub department as the non-participant, was then approached. All participants were teachers in the bachelor's, several of them having many years of experience teaching this bachelor's and some younger teachers with a couple years of experience. Together they taught courses in every year of the bachelor. One of the interviews was held in English, the others were held in Dutch, based on the preferred language by the participant.

## 3.2 Data collection

### Data collection methods

At first a pilot interview was held with the second supervisor of this study and his feedback was implemented in the final version of the interview guide. This second supervisor has taught courses in this bachelor's for many years and is a professor in science education. The interviews held after this pilot interview did not prompt any changes to the interview guide. Interview length of half an hour was chosen, to accommodate for limited teacher's availability while still ensuring in depth responses. A copy of the interview guide has been included in appendix A.

### Data collection instruments and technologies

All recordings were stored and used locally, on any device used by the researcher. The voice-recordings were recorded with the researchers mobile phone connected to a USB-microphone. These recordings were then transferred to the researcher's laptop, encrypted by BitLocker, through a USB-cable. The recordings were then transcribed manually on this laptop. These transcriptions were final and have not been returned to participants for comments or corrections.

### Interview set-up

In the introduction section 1 and the related work section 2 we have established important topics and themes for implementing sustainability in a CS bachelor's. A baseline of the current state of sustainability in the Radboud University CS bachelor's is required before advice can be constructed for this CS bachelor's. This is not very straightforward as the term 'sustainability' can mean different things to teachers. It can be a narrow view of resource re-usage or a broad view that incorporates ethics. It can still mean different things to teachers in a narrower context, when we try to define 'sustainabil-

ity in CS'. Does this mean energy usage? Does this mean longevity or bias of software produced?

Looking at teaching sustainability in CS, this research explores the different views and opinions that teachers from the bachelor's programme have of this topic. This is done through semi-structured interviews, to incorporate the major points mentioned above, but leaving the freedom for the different approaches that teachers could have to teaching sustainability in CS. As there was no overview available about what was currently done in terms of teaching sustainability, the interview had to start with establishing this. First the teacher was asked to give a definition of sustainability and then asked what this teacher currently did for their definition of sustainability. The definition of sustainability was explicitly left open to teachers themselves, to have the interviews paint a more realistic picture of the bachelor's. Other perspectives of sustainability were brought up by the researcher after the teacher's response to make the results comparable.

The interviews started with a part where teachers can comment on the topic of sustainability in CS and how this relates to the CS bachelor's at Radboud University. Teachers were asked about its current state, its origins and what it could look like in the future. This ensures that possible advice constructed from these interviews takes into account past, present and possible future of teaching sustainability in CS. Teachers were prompted about some of the sustainability themes like resource usage and energy usage and if or how it relates to the CS bachelor's. They were also asked whether they had a view of sustainability that included a broader view on sustainability, including ethical issues or a narrower one.

The main interview questions can be seen in the boxes below, follow-up prompts to a question are shown in *italics* in the same box.

The interview started with a broad question:

> What does sustainability (in the context of CS) mean to you?
> *For example, (reaching SDG's, dealing with climate change, preparing students for future challenges)*

This question had two goals, establish the teacher's knowledge of sustainability in CS and understand their view on sustainability in CS in general.

The next question prompted was then:

> What do you want your students to learn regarding sustainability and CS?
> *For example, (sustainable production, energy usage, bias & inclusion, autonomy, democracy, accessibility)?)*

This question tried to tie in the themes occurring in the literature. For

example, are teachers focused on creating awareness or how social issues are related to CS solutions? Or possibly different themes that the researcher had not found yet? For teachers that were more unfamiliar to the subject extra prompts were given by the researcher.

This was followed up with what teachers though was currently being done in the bachelor's in general:

> Do you think sustainability is included enough in the CS bachelor's?
> *Why (not)?*

The final question for this part of the interview then prompted teachers how they would include sustainability in the bachelor's. This question aimed to see how teachers looked at the future of sustainability in this bachelor's.

> How would you include sustainability in the CS bachelor's?

Then there was a second part of the interview, where the questions went more into teacher's own research and education area and their considerations for (not) incorporating sustainability into their course(s).

The starting question asked teachers whether they even had the knowledge to start including sustainability in their courses:

> Do you feel knowledgeable enough to include sustainability in the course(s) that you teach?
> *What kind of knowledge do you think you are missing?*

This question aimed to see whether teachers already considered sustainability topics. This was followed up with why they did or did not do so. In case they already did so they were also asked to give concrete examples of sustainability in their course.

> Is sustainability something that you currently (try to) incorporate in your teaching?
> *If yes, how? Do you teach about sustainability, do you activate students to work on sustainability in CS in practice or neither?*
> *Can you name some concrete examples?*

A following question focused on the future of sustainability in the bachelor's:

> Do you want to do more with sustainability in your teaching?
> *If yes, what are the challenges in accomplishing this?*
> *If no, why not?*

The idea behind this question was that it would prompt teachers to explain possible considerations on why sustainability does or does not deserve a place in the courses that they teach. The remaining questions focused on the requirements to make inclusion of sustainability in the bachelor's possible.

> Would you like to receive support in including sustainability in the course(s) that you teach?

Teachers could expand on whether they were missing knowledge and would like more training or whether they perhaps needed more guidance from the education board to tackle this subject or other practical requirements that could help the inclusion of sustainability in the curriculum.

A final question was open ended whether teachers wanted to mention anything about the topic that the interview did not cover. The full interview guide has been included in appendix A.

## 3.3 Data analysis

The transcripts were compared to the original themes and subjects found in section 1 and section 2, summarised in figure 3.1.

It was then noted where participants deviated from these themes and which answers were not covered yet through a second analysis. In the second analysis new topics were identified by establishing major talking points that were not covered by the original themes and subjects. These were then compared throughout the interviews and grouped together when they were very similar. This second analysis lead to the renaming of several topics and

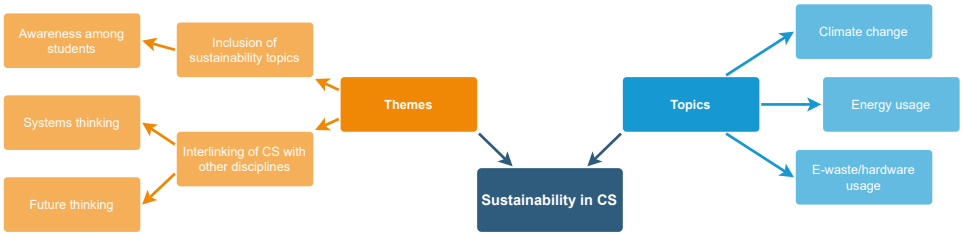


Figure 3.1: The topics and themes that have been discussed so far can be combined to form the basis of the analysis

the creation of two new branches, approach and requirements for teaching sustainability in CS. The second analysis provided a complete overview of the participants' opinions and views on sustainability, as can be seen in the section Results 4 in figure 4.1.

## 3.4 Ethical concerns

### Researcher characteristics and reflexivity

The author and sole researcher of this thesis is a male fifth-year computing science student at Radboud University. The researcher has limited experience in teaching as a teaching assistant and in other supporting roles within the university. He has a clear understanding of the workings of the university and the process of implementation of education policies through co-determination participation. The researcher followed almost the entire bachelor himself and is not unfamiliar with the participants. Some of the participants knew the researcher already as a student or study association member.

### Ethical concerns pertaining to human subjects

If a participant responded positively to the in-person request to participate in an interview for this research they received a consent form over mail that they then had until the date of the interview to read through. At the start of the interview they were asked to sign this consent form before proceeding. The consent form had an optional consent option to remove some of the anonymization offered by default as the researcher hoped to analyze some of the data by subdepartment or research field. As only few participants used this option this was not used in the analysis and all interviews were fully anonymized. The interviews were voice-recorded after physical signing of the consent form. A copy of the consent form has been included in appendix B.

# Chapter 4

# Results

After the interviews have been held, the basic diagram 3.1 established in chapter 3 has been updated and expanded based on the results from these interviews into figure 4.1, the full diagram. The full diagram encompasses all the teacher's input gained through the interviews. In this section there will first be an explanation on the views of teachers on the sustainability topics and on the literary themes in the diagram. The interviews then led to the creation of two new sections in the diagram: approach and requirements for implementing sustainability in the Radboud CS bachelor's programme.

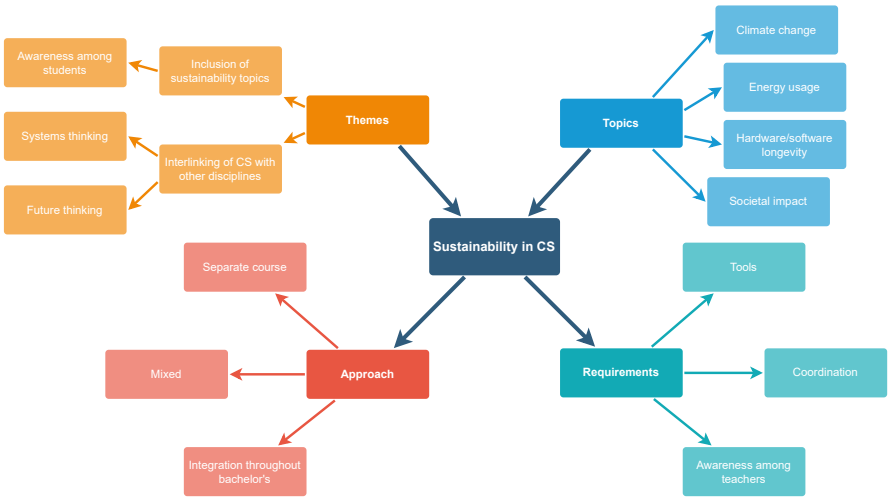


Figure 4.1: An expanded diagram that takes teacher's input into account

## 4.1 Teachers' views on the literary themes

### Interlinking of CS with other disciplines

On this subject there was a clear difference between the curriculum level and the course level. On the curriculum level teachers agreed this was a very important subject that has to be tackled in the bachelor's. How we deal with the limited resources that we have and the impact of climate change were seen as very relevant subjects to CS. Preparing students to deal with the complex consequences of climate change but also developments like artificial intelligence (AI) and its energy usage were all acknowledged as relevant to the bachelor's as a whole.

On the course level, however, teachers were mixed on the topic. Some teachers saw limitations for including a broader view of CS. Often named limitations were mathematical and security course subjects that are too abstract to include sustainability aspects. Data science courses were considered too basic to consider sustainability aspects. There was less necessity to name the interlinking of CS with ethics or law related aspects as there are already courses that tackle these subjects. It was also mentioned that the bachelor's is already quite full and other subjects would have to be limited or removed to be able to spend time on sustainability.

Other teachers were more positive about the opportunities for including

sustainability aspects. One teacher named the possibility to include energy usage tools in lectures and assignments, although that was not being done yet. One of the other teachers mentioned already spending a lecture on ethics in one of their courses and was considering making a project that deals with sustainability in that course. Another teacher saw possibilities for a separate 'sustainability in CS' course that could tackle this subject.

There were also several teachers that did not know how to tackle this subject yet, also in their own courses. They too found it relevant to include in the bachelor's but did not have concrete ideas on how and where.

Several teachers mentioned that sustainability aspects are too difficult to include but they could name other courses that should be able to do it more easily. The teacher of one of these other courses then said that this course was also not suitable for including sustainability aspects. It may be that including sustainability aspects in practice is a bigger challenge than it seems from a distance.

### Inclusion of sustainability topics

A majority of teachers acknowledged the importance of creating awareness of sustainability in CS among students. Teachers mainly want students to be aware of the energy they consume. Some teachers also wanted students to be more aware of the impact of CS in general. Teachers gave examples of CO2 emissions, societal impact and maintainability of code. One teacher framed this as the knowledge that when you can solve something fast, it is not always the optimal way for society as a whole. Every teacher that mentioned awareness also stated that this was not currently being done (sufficiently) in the bachelor's. They based this on the fact that very few courses include sustainability topics but several teachers did mention the desire to do more with this in the future.

## 4.2 Teachers' views on the sustainability topics

### Energy

Energy usage was a major topic in every interview and one of the first subjects teachers mentioned as important to sustainability. Teachers deemed reducing energy usage and teaching the relevance of energy usage in CS solutions to be very important. One teacher mentioned that they already spent an entire lecture on this subject in one of their courses and considered doing more than this lecture. This topic was often accompanied by a reference to AI and its major energy usage impact with large language models and deep learning, especially compared to more traditional computing methods.

### Climate change

The other unanimously named topic was climate change and the responsibility to consider the emissions caused by algorithms and models that were being taught, but also the impact of projects done by students that use a high amount of energy. Teachers related this to energy usage and the importance of both reducing energy usage and emissions of CS solutions. It has been separately named in this section as it was seen as a larger subject than energy usage. Teachers were very sure about the relevance of CS in general to climate change. Teachers were much less sure about the relevance of specific courses to climate change. Some teachers pointed out the abstract nature of some of the math heavy courses in the curriculum, but also the courses that were cryptography related were at times seen as too abstract to include climate change as a relevant aspect. Data science related courses were seen as more relevant courses for this sustainability topic.

### Longevity of hardware & software

It turned out that hardware was a minor theme during the interviews and a greater focus was on software.This topic has changed names from the diagram used to construct the interviews. Teachers were referring to software solutions and development tools that are being used throughout the bachelor's as products. The longevity of these products used in the bachelor's was mentioned by a majority of teachers. Teachers wanted these tools to not only be more energy efficient but also to be more clear about energy usage and $CO_2$ emissions during usage.

Making software that needs less maintenance and fewer updates to continue working was seen as a sustainability topic. This was another aspect of longevity and how future oriented the development of software and hardware is.

A minor theme was the consideration of hardware usage by students. This was only concretely named by one teacher but alluded to by several others. Teachers gave examples of data centres and the servers used for large language models like ChatGPT. Especially the use of hardware solutions that students connect to from their own device can be energy intensive while the student using this hardware is not made aware of this fact.

### Education of societal impact

This was seen as an important topic for CS but not a sustainability topic. Teachers pointed out that this topic is already being covered by several other courses in the bachelor focusing on law and ethics. Some teachers, however, did find this an important sustainability related topic but also recognized the attention that was already being paid to it in the existing bachelor's

courses. These teachers also named the possibility for all these courses to fall under one sustainability approach for greater impact.

## 4.3 Requirements

This is a new insight that arose from the interviews. For the implementation of sustainability aspects to be a success, teachers named several requirements. These will be explored in the following paragraphs along with the problems they would solve for teachers.

### Tools

As energy usage was a major point raised by teachers, they talked about needing a way to teach students how to consider energy usage. Several teachers named the desire to do so but that they were missing the tools for it. An easy integration with education in the bachelor's so that students can incorporate energy usage as an aspect in a project or assignment was named as a must have. One teacher mentioned wanting students to have an entire lecture on energy modelling in a course, although this teacher did not know which course this would be suited to.

Interestingly, one teacher mentioned that for their area of research these tools were already readily available and it was just a matter of implementing them in their course. This was different to teachers in other areas of research where these tools were not yet available or not precise enough.

### Coordination

Coordination was mentioned by several teachers as an important part of successfully tackling sustainability. If a sustainability project guides and pushes them to work on the subject several teachers acknowledged they would then make it happen. One teacher mentioned the fact that if they did not teach any courses they would still be busy for 40 hours. To them it was a matter of prioritising.

One thing a teacher talked about is that teachers should be wary of repeating the same subjects to students throughout courses, and students getting tired of sustainability, instead of enthusiastic. This could also be tackled by coordinating the staff and having a joint approach.

### Awareness among teachers

The general awareness for sustainability in CS appears to be growing among teachers with every teacher acknowledging that there should be more attention to the subject where there is currently very little. An important part of why sustainability can be seen as an underexposed aspect of this bachelor's is

because it was simply not that big of a theme in the past. Especially themes like climate change and emissions caused by CS are new and only considered by teachers since recently. The awareness that can be created among students first has to exist among teachers to be able to teach students about sustainability. This can be done in various ways. Some teachers mentioned wanting their research to have more sustainability aspects. Other teachers also mentioned PhD's and thesis supervision as a potential area for research with more of a sustainability focus, with the possibility of developing the aforementioned energy usage tools here.

No teachers mentioned that they felt they were missing knowledge on the subject. There is missing knowledge in terms of research that still has to be done towards this subject but they did not feel they required more training or education on sustainability themselves.

## 4.4 Approach

Three approaches to implementing sustainability aspects were mentioned in the interviews, one of them being a combination of the two.

### Separate course

Some teachers pointed out that a separate course on sustainability could be made where many of the sustainability aspects could be tackled. This approach is very similar to the societal aspects courses that are already in the bachelor's with their own flaws and benefits. Teachers mentioned the downside of purely non-technical courses that are often dismissed by students on the basis of being fluff. It can also feel very disconnected from other courses.

The benefit would be that you have full freedom to explore sustainability in CS and are not limited by the scope of a specific course. Another benefit would be that it is easier to develop since it does not need coordination from other course teachers.

### Integrated in the bachelor's

There is also a more difficult approach where sustainability aspects are integrated throughout the bachelor's. This was named by some teachers precisely because of the downsides of a separate course. Incorporating this subject in existing courses means that students will be more engaged since it is directly applicable to technical aspects of CS. You would then, however, be more bound to the scope of a course. It is also much more effort to develop because it needs an integrated approach from staff together to start up. After that it will need more coordination to maintain since sustainability in CS is a new and developing subject.

### Mixed

An approach that aims to balance the benefits and downside of the previous two themes is a mixed approach. By doing both a separate course and an integration with the entire bachelor's you will have the freedom to explore sustainability in CS whilst guaranteeing that students will be more directly engaged with the subject in specific courses. This still requires an integrated approach from the full staff but may be more manageable to maintain as this responsibility can be held more by the coordinators of the separate course on sustainability in CS.

# Chapter 5

# Conclusions & Discussion

This paper aimed to answer the question: *What are teachers' stances on sustainability in the CS bachelor's at Radboud University and how can sustainability be incorporated in the future?* By conducting interviews with nine teachers, who teach at least one course in this CS bachelor's, their views, doubts and approaches to sustainability in CS were explored. Sustainability in CS can be divided in important themes, for example how CS is linked to other disciplines, and topics, for example energy usage. These themes and topics require proper tools, coordination and a growing awareness among staff. Teachers named having the proper tools, a coordination of the staff and awareness among teachers as important requirements. The approach to educate sustainability in the bachelor's did not have a clear best option, but rather three different options with benefits and drawbacks for each.

One of the main takeaways of the interviews is that sustainability should and could have a place in the bachelor's. Some teachers want to do more but await coordination and some teachers do not know at all how to tackle this subject. On the other hand, others see quite some drawbacks but they also name possible ways to solve it. Every single participant that was interviewed, however, named sustainability as a subject that has to be included in the bachelor's.

How it should be included is something that still has to be figured out, together. The three approaches (a dedicated sustainability course, sustainability integration throughout the bachelor's or a mix between these two) mentioned in the results can all be successful if the drawbacks and benefits for each are taken into account. The mixed approach seems the most valuable for teaching students a deeper understanding of sustainability in CS, but it also requires the most effort from the staff. This is because you need at least one dedicated teacher for the course but also a structure in place to coordinate how sustainability is tackled throughout the bachelor's.

It may be that committing to the one course approach on the short term and expanding to an integration throughout the bachelor's provides a good balance of time and resources available for this subject.

Which sustainability topics should be included, in the opinion of the teachers, is more straight forward. Energy usage was the main subject brought up by teachers, from all sub departments. This should be seen in the context of climate change and how limiting energy usage can also lead to limiting emissions. The longevity of software and, to a lesser extent hardware, is another aspect that can be focused on.

Teachers should be supported in these topics in several ways. Firstly by the proper tools. The main type of tool requested by teachers was integrated energy measuring with easy incorporation into lectures and projects, a tool that does not exist yet according to teachers. Secondly, coordination among staff is important to push and guide teachers in implementing sustainability aspects. This can be done through regular staff meetings and appointing coordinators among the teachers who have dedicated hours to assist other teachers. Thirdly, more research into sustainability topics by not only researchers but also PhD students can help with the creation of aforementioned tools but also to create a better understanding of sustainability in the CS field. It should also lead to more awareness among teachers for what CS can mean in terms of sustainability.

## 5.1 Reflection on findings

As mentioned in section 2.2, there are three sustainability perspectives. Teachers in this bachelor's mostly take on an incremental perspective. Teachers recognize that change is required and they believe that this is possible within the currently existing frameworks, the curriculum as it is now and its current courses. Possible ways to to do this are for example updating lectures or introducing new projects. They also take on an enabler perspective, seeing that computing science should take on a wide perspective that takes into account economic, environmental and social goals. This conforms with Easterbrook's approach of transforming from computational thinking to systems thinking from section 2.1. Teachers saw the value of taking these various aspects into account when teaching computing science. The disruptive perspective has not been present in the interviews as teachers did not call for radical change in our current approach to computing science.

Finally, the mere inclusion of sustainability already has an impact on students and this could have a knock-on effect on the development of sus-

tainability education in the future, as mentioned in section 2.1. The three approaches to including sustainability may all prove valuable for creating awareness among students.

## 5.2 Reflection on methods

The researcher had no prior experience in qualitative research and it is not a type of research that often occurs within the computing science study programme that he followed. Looking back at the various design and process decisions that were made this research could have been done more structured and should have been more grounded in qualitative research theories. It does not make the research results less valuable but they will be more difficult to compare and generalize against other studies.

## 5.3 Research limitations

These interviews were a snapshot of the current state of sustainability teaching in this bachelor's. These interviews were taken in the span of several weeks and reflect the state of sustainability teaching at that time. Since this is a developing subject, having the same interviews a year from now could already lead to different results.

The interview participants gave varied responses on some subjects but very like minded responses on others. There were nine teachers interviewed out of the 47 teachers total (S. Meeuwsen, personal communication, December 12, 2023) teaching in the bachelor's ( 20%) and the sample of teachers was evenly spread over the various sub departments in iCIS. There may be some different opinions among the general staff that have not been considered in this study, but their input should in general be applicable to the entire staff. Since Radboud University has a university wide project on sustainability in education[12], this study could also be relevant to the university in general. Especially to studies closely related to the CS bachelor's, like mathematics and CS masters. Since the participants were only asked about the CS bachelor's and were only sampled for teaching in this specific bachelor's programme, these results are not directly applicable to other study programmes. The same generalizability issue holds for CS programmes outside the Radboud University.

The interview guide did not have any questions pertaining to the involvement of students specifically. All the questions were asked from the perspective of a teacher, as the research question was also focused on this aspect. Whether this was the only reason teachers did not mention the stu-

dent perspective at all or whether this is an aspect teachers do not consider is unclear.

## 5.4 Future work

Since this is a first attempt at describing sustainability in CS at Radboud University, quite some questions remain.

- Firstly, how will this develop in the future? It may prove valuable to repeat this research over the coming years to measure the development of teaching sustainability aspects and the awareness among teachers and students on this subject. This becomes more valuable when combined with the development of one of the approaches described in chapter 4.4 and measuring the effectiveness of a certain method of teaching sustainability in CS.
- Secondly, do these results also apply to other study programmes? Among the Faculty of Science programmes at Radboud University this is the first study to perform this experiment and it would be valuable to gain the insights from other study programmes. By using a new sample pool, for example teachers from a specific master's or other bachelor's programme, the results from this study can be better generalized.
- Lastly, something that was not mentioned by a single teacher was student involvement and how they could or should be involved in this process. Teachers had very elaborate opinions on tackling this subject with the staff and how to do it themselves but no one considered involving students in the process. It can actually be very valuable to get insight from students on which sustainability topics would motivate them and what sustainability aspects they are currently missing in the bachelor's.

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# Appendix A

# Interview Guide

*Prompts in italics are for extra probing, if necessary*

### Teachers' vision on sustainability in CS (10 minutes)

What does sustainability (in the context of CS) mean to you?

*For example, (reaching SDG's, dealing with climate change, preparing students for future challenges)*

What do you want you students to learn regarding sustainability and CS?

*For example, (sustainable production, energy usage, bias & inclusion, autonomy, democracy, accessibility)?*

Do you think sustainability is included enough in the CS bachelor?

*Why (not)?*

*How would you include sustainability in the CS bachelor?*

### Teachers' implementation of sustainability in their teaching (10 minutes)

Do you feel knowledgeable enough to include sustainability in the course(s) that you teach?

*What kind of knowledge do you think you are missing?*

Is sustainability something that you currently (try to) incorporate in your teaching?

*If yes, how? Do you teach about sustainability, do you activate students to work on sustainability in CS in practice or neither?*

*Can you name some concrete examples?*

Do you want to do more with sustainability in your teaching?

*If yes, what are the challenges in accomplishing this?*

*If not, why not?*

Which sustainability values are currently included in your courses?

*For example, (sustainable production, energy usage, bias & inclusion, autonomy, democracy, accessibility)?*

Would you like to receive support in including sustainability in the course(s) that you teach?

*If yes, How would you like to receive support?*

### Finishing question (5 minutes)

Are there other things you would like to mention regarding sustainability in computing science education?

# Appendix B

# Consent Form

## B.1 Research and researcher

My name is Mark de Jong, I am a bachelor student computing science and the sole researcher for this bachelor thesis project. The thesis aims to define sustainability in computing science education at the Radboud university and how/if sustainability could be further implemented. The first part of this thesis consists of interviews with teachers from the Radboud computing science department.

## B.2 Personal data

To conduct the research it is necessary that your personal data are collected, used and stored in the form of an audio recording. Personal data refers to information with which you can be identified directly (your name or the courses you teach) or indirectly (your department or your opinions on education within your department) as a person.

### B.2.1 Audio recording

For the current research it is necessary to make audio recordings to answer the scientific research question and to publish the results. The audio recordings are collected only for scientific purposes, namely for the purpose of creating insight into the current state of sustainability in computing science education at the Radboud university. The audio recordings will not be shared by the researcher. The audio recordings are converted to transcripts. Parts of this transcript can be used in published form (such as in journal articles and in books). By default, the transcript will be anonymized (see optional consent).

## B.3 Data storage

The audio recording collected by the researcher will only be accessible to the researcher. The data is stored on an encrypted drive.

## B.4 Data retention

The audio recordings will be deleted 3 months after the thesis has been submitted. Anonymized transcripts will be kept for up to 10 years in a Radboud university research repository.

You have the right to withdraw from the research until the thesis has been submitted by sending an email to mark.dejong@ru.nl. Your personal data will then be deleted and no longer included in any part of the research. After this period your research data can no longer be deleted.

## Consent form

for participation in scientific research: Sustainability in CS education at Radboud university

I herewith confirm that:

- I have been satisfactorily informed of the study both orally and in writing;
- I have read the written information;
- I have been given the opportunity to ask questions about the study;
- My questions have been answered satisfactorily;
- I have been given ample opportunity to think carefully about participating in the study;
- I participate in the study entirely on a voluntary basis.

I understand that:

- I have the right to withdraw my consent at any time without having to state reasons and without fear of adverse consequences by contacting Mark de Jong at mark.dejong@ru.nl
- I have the right to have my research data deleted until the thesis is handed in
- I have the right to withdraw my consent for the (further) processing of my (specific) personal data; my personal data are processed in accordance with the applicable European privacy regulations;
- My personal data are processed in accordance with the privacy statement of Radboud University (https://www.ru.nl/english/vaste-onderdelen/privacy-statement-radboud-university/);

**Mandatory consent to participate in research**

**I give explicit permission for processing audio recordings**

**I agree to participate in the study**

Name:

Signature:

Date:

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**To be completed by researcher**

Name: Mark de Jong

Signature:

Date:

Pseudonym used in transcripts:

## Optional consent (To be filled in after interview)

*These are not necessary to participate in the research, it could however lead the researcher to draw better conclusions from the data.*

□ I give consent to reveal my department in the transcription, this would make the research data indirectly traceable to me.

□ I give consent to reveal my name in the transcription, this would make the research data directly traceable to me.

**Participant**

Name:

Signature:

Date: