A Computing Education Approach for Geography Students in Context of GIS

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***Abstract*—We present an educational design for an undergraduate university course meant to engage Geography majors with computing and computational thinking. For that matter, we use the pedagogical principle of contextualization, relating computing topics to the discipline of Geography using climate change modeling with geographic information systems as a context. Following a design-based research approach, we first present considerations and arguments that form the basis for our educational design, and then discuss initial results of implementing and teaching a corresponding course to Geography Education majors.**

Keywords—Computing Education; non-CS students; contextualization; design based research; Geographic Information System.

I. Introduction

The relevance of computing education has been recognized in many countries by stakeholders and policy makers. This lead to nation- or state-wide programs and initiatives to introduce computing in secondary or even primary education, see for example [4][20][29][35][23][33]. However, for the long-term success of these initiatives a sustainable pipeline of computing teachers seems to be the most crucial factor and remains a challenging endeavor to be accomplished [6][8][25][38].

While computing is still being established in primary and secondary education, digital transformation of our societies and the economy continues to accelerate. As a consequence, current generations of graduate students need to acquire computing literacy. For example, in the field of Geography computing oriented technology has been introduced in the past decades to collect, analyze and visualize data related to geographical phenomena and problems. As this technology embodies computing principles, methods and approaches, it also mediates geographical activities yielding to computational thinking [18] within the discipline of Geography. This can be observed particularly with Geographic Information Systems (GIS): They are a major carrier of geographical and computing knowledge and allow modeling and analysis of geographical information with spatial databases and related algorithms. Comparable development can be found in almost every academic field. For example, and beyond traditional STEM disciplines, both the humanities and education experience the same transformation (e.g. through the introduction of digital libraries and archives or learning management systems and learning analytics for online education). As a result, current university students require computing literacy just like primary and secondary school students. However, for tertiary education the implicit expectation is also to transfer and contextualize computing literacy within a specific discipline. Geography graduates, for example, are not only required to be able to use a specific GIS, but also are expected to have a basic understanding of data structures and modeling, database design as well as algorithms for spatial data analysis. In addition, GIS-related job offers also expect geographers to have programming skills [2]. In other words, students are required to acquire domain-specific computing literacy and the ability of thinking computationally within their discipline.

At many universities, Computer Science (CS) departments offer CS courses for non-CS majors. These offers usually address majors from STEM-disciplines and comprise single service courses and/or a whole “CS minor”-curriculum. Minor programs are usually non-mandatory and attended by a minority of non-CS majors, who are particularly interested to learn programming and pursue Computer Science education. Very often, the majority of these students is also majoring in a STEM-related discipline, mostly Mathematics or Physics. Responding to the increased need for computing education, several course designs have been introduced recently to attract more non-CS majors and engage them better with CS education, for example [1][12] [26]. However, only few examples can be found that target students who are *not* specifically interested in CS and possibly unaware of the need for computing literacy to successfully progress their studies and future careers. One of the rare examples is the media computing course at Georgia Tech [16]. Also, very few approaches can be found that directly focus on addressing computing education within non-CS students’ disciplines like [13][26]. They successfully attract non-CS students to engage with computing while creating awareness for required comparable approaches in other disciplines.

Following this line of reasoning, we argue that as a first stepping-stone towards engaging more non-CS students for computing education, corresponding offers need to be integrated within regular courses of students’ majors and be focused on digital technology that is pervading the discipline while giving particular reason for studying computing. For that matter, we have started creating an educational design for potential undergraduate courses meant to engage Geography majors with computing and computational thinking situated within their discipline and focusing on GIS. Situating computing education

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in other disciplines requires pedagogy that particularly focuses on knowledge transfer, domain-specific competency development and the specific role that digital technology plays in the field-specific subject matter. Context-based pedagogy addresses these questions in part [19][24] and we chose this approach for our educational design.

In our research project, we follow an educational design research approach [27]. The latter (which also goes by the name Design-based Research) has its roots in design research, which focus on designing and investigating instructional interventions and learning environments in the settings for which they are intended, with the dual purpose of developing and refining theories of learning as well as testing and revising the design itself. A central feature of design research is a reliance on iterations of intervention, analysis, and redesign in four interrelated phases to allow researchers to test, revise, and refine conjectures. As part of a preliminary iteration, we have accomplished the first two phases (problem analysis, design and construction) and are currently in phase three, evaluation and reflection of a first testing. In this paper, we will introduce the results of this first iteration, i.e., considerations regarding the educational design and its testing. Hence, this paper neither is representing a theoretical research result nor is it an experience report. It is explicitly a design-based research paper, with the purpose of presenting those theoretical considerations most relevant to the development of the intended educational design and combining it with preliminary insights of implementing and teaching a related course.

In the next section, we will introduce GIS and outline how it is related to computing and computational thinking. In section III, we will discuss content- and pedagogy specific constraints for creating computing-oriented GIS Education. In section IV, a course syllabus and teaching experiences are reported. The paper concludes with section V.

II. Geographic Information Systems: A Case for Computing Education

Geography as an academic discipline with undergraduate and graduate education programs exemplifies very well a case for computing education in context of another discipline. In this section, we will extend on this argument briefly introducing the digital transformation that has taken place since the 1960s in this field. We will focus particularly on GIS that embody computing concepts and principles and therefore require computing education.

A. Digital Transformation in Geography and GIS

Geography as a science studies the social and environmental phenomena of geographic space and research interests can cover vast spaces and a multitude of geographic phenomena. For that purpose, facts linked to a location on the Earth`s surface and to a point in time need to be collected and analyzed [34]. This geographic information is the main component of geographic research and for many years was time-consuming as well as difficult to obtain due to inadequate computation methods and limited data-handling. Starting with the development of the first GIS in the 1960s, a major transformation took place within the scientific field of Geography and lasts up to this day [10][15].

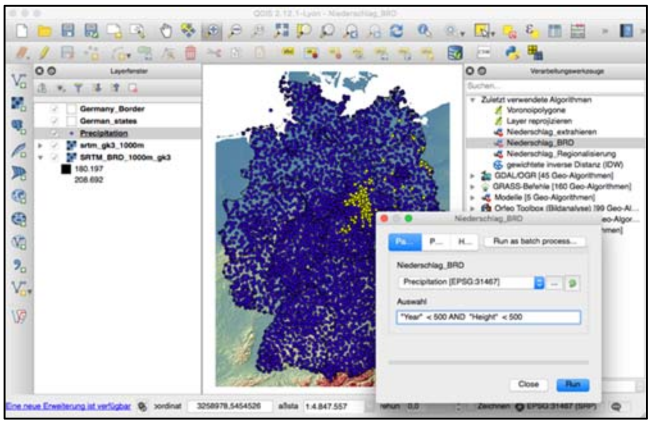

Figure 1: Screenshot of QGIS showing data selection using SQL on the example of precipitation in Germany based on data obtained from the National Meteorological Service (Deutscher Wetterdienst, DWD).

TABLE I. Computing-related Learning Objectives from the GIS & T Body of Knowledge

Knowledge Area	**Core Units**
Data Modeling	• Basic storage and retrieval structure • Database management systems • Vector and Raster data models
Data Manipulation	• Representation transformation • Interpolation • Data model and format conversion • Vector-to-Raster conversions
Design Aspects	• Database design • Analysis design • Application design • System implementation
Analytical methods	• Query operations and query languages • Basic analytical operations and methods
Geo-computation	• Computational aspects and neuro-computing • Cellular automata models • Genetic algorithms • Agent-based models • Simulation modeling

The introduction of new computing oriented methods for data collection and data analysis (e.g., remotely sensed data through satellites, global positioning system (GPS) for methods of positional control or image classification and pattern recognition) help geographers to automate processes and support spatial analysis [34]. Reduced prices for computing hardware in the early 1980s helped sustain a software industry and promote the development of cost-effective applications as it happened and continues to happen in almost all industry branches.

A GIS is an information technology system consisting of a spatial database with an interface for entering, processing, and visualizing data related to locations on Earth [21]. Earth-related locations are defined as geographic information and are described by spatial and time information that refers to forms and processes of phenomena that are observable on Earth. Earth-related phenomena can vary in nature and cause, e.g. precipitation is a climate related phenomenon while migration is a geopolitical and socio-cultural phenomenon. Data visualizations in GIS resemble maps but GIS is more than the digital version of a paper map. It offers a multi-layer representation of spatial processes referring to potentially different dimensions and granularity. Visualized data are stored with raster and vector graphics allowing different formats and data analysis procedures. SQL statements for data retrieving can be entered through the interface, see example in Figure 1. The field of spatial computing offers different algorithms built into the system and most GIS also provide opportunities for creating additional computer programs. This interrelation between CS and Geography is also reflected in the Geographic Information Science and Technology Body of Knowledge, a model curriculum defining outcome-based educational standards for GIS education from the undergraduate to the professional level [11]. It comprises specific knowledge, skills and applications structured within 10 knowledge areas and more than 1600 educational objectives. In TABLE I. we have summarized those computing-related objectives that do not specifically point to Geography emphasizing the interrelation between computing and GIS.

B. Current GIS Education

GIS play an important role in geographical work and also in secondary education, GIS has been recognized as an important technology for the subject of Geography and, therefore, has been integrated into related Educational Standards (e.g., in Australia, United States, and Germany) [22]. Responding to the relevance of GIS, universities world-wide offer introductory and advanced courses in GIS in corresponding undergraduate programs of Geography. However, GIS educators are concerned with the implementation of technology and methods associated with GIS, the effectiveness of instruction and the impact of attitudes and behaviors as fully elaborated pedagogical designs are still missing [2]. As research studies on how GIS is exactly taught in specific schools nationwide are missing, an overall picture is difficult to draw upon. Giving the different open challenges for GIS Education described in [2] and further suggestions for GIS Education standards [11] where computing education is not mentioned, it can be assumed that a regular GIS course offered for geography students and taught by a geography faculty focuses more likely on specific use-case training rather than computing related topics.

At the University of Hamburg GIS the situation is comparable and courses for Geography students tend to focus on geographical problems while providing an extensive though highly contextualized training of how to use and apply ArcGIS Desktop (a commercial GIS for industry and science purposes) for geographical purposes. Many report back that they lack interest and motivation to become acquainted with ArcGIS Desktop and that they have problems understanding related activities with the tool. For pre-service Geography teachers, attending the same introductory course to GIS, interest and motivation to become acquainted with ArcGIS Desktop is even lower. Anecdotal evidence shows that they relate GIS with scientific and industrial work and do not perceive the technology as an additional opportunity or tool to design meaningful Geography Education in secondary schools. Based on our previous arguments above, we hypothesize that this situation also reflects students' need for computing literacy within their major and in consequence requires an educational approach that includes relevant computing topics while providing relevance and motivation to study them.

III. Creating Computing-Oriented GIS Education

In the previous section, we have outlined the relevance of computing education in context of GIS education and the need for concrete educational approaches and related pedagogies. In creating a new educational design that is addressing all undergraduate geography students, particular attention needs to be given to student engagement, as it can be assumed that they do not have a particular interest and motivation for studying computing. In this section, we will discuss first how contextualization is useful to engage and motivate students for studying computing in context of GIS and second, how to choose relevant computing topics for a potential computing-oriented educational approach with GIS.

A. Contextualization

From several studies in computing education and gender research, we know that students not having strong affiliations with technology and/or CS often require meaningful justification for why they should learn about and become engaged with specific digital technology and related computing concepts, see for example [14][30][31]. For that matter, context-based approaches have been suggested, e.g. [16][17][24][36]. The general idea is to contextualize domain-specific knowledge, i.e., concepts, theories, or approaches within meaningful topics and related questions or problems. Contextualization prevents learning of isolated facts and provides relevance and meaning. It has a positive impact on student engagement, interest and motivation. As our educational design is supposed to address student engagement and motivation for studying computing in context of GIS, we chose contextualization as a pedagogical approach. For that matter we distinguish GIS as the meaningful context for computing concepts.

Context-based approaches have certain disadvantages: The context is additional knowledge that might distract students from the actual learning content while creating content-overload. Additional teaching time needs to be spent on introducing and discussing the context. Furthermore, knowledge transfer is particularly challenging as students have to distinguish between the context and the domain-specific knowledge. Additional time is required to teach decontextualization and knowledge transfer, the latter however needs also to be addressed in traditional teaching. In using a regular GIS course as a context for computing education, most of these issues can be resolved. Studying a GIS is part of geography education and therefore no additional knowledge that might cause distraction or require additional teaching time. Decontextualization and transfer are less challenging as students are already learning computing concepts applicable to their discipline. However, these issues remain open while creating the educational design and only additional empirical inquiry will provide evidence how these questions can be solved best.

While we understand GIS as a meaningful context for studying computing, we also believe that GIS itself needs to be contextualized within the discipline of Geography in order to provide additional relevance and meaning for students to interact with the tool. The German computing education community has suggested a context-based approach for secondary computing education called “Informatics in context” (Informatik im Kontext) [24]. This approach relates computing concepts with digital technology and application software that students can encountered in specific use situations of their every day life. These use situations create a multidimensional context in which computing as well as non-computing related questions are asked. For example, a social media platform like Facebook has a technical, social, ethical, judicial, esthetical as well as economical dimension in which several use situations can occur for those interacting with the application (How do they store data? What is data storage and data security? If it is for free, who is paying? Etc.). Certain use situations with Facebook can be aligned to questions in which the computing technology used for Facebook enables and fosters specific forms of communication (see also teaching-unit example with E-Mail [17]). We draw on this particular approach for context-based pedagogy, using it contextualize GIS with Geography.

B. Computing Concepts in GIS

Creating an educational approach that introduces GIS with related computing concepts, the question is: What are the criteria for deciding on computing topics and related learning objectives? The introduced GIS standards in Sec. II represent a very good framework for relevant computing concepts that the GIS education community acknowledges. Approaching the question from a computing education perspective, corresponding standards can be used as well to determine relevant computing concepts. Currently, CS Education standards have been presented in several countries (e.g. by the Computer Science Teachers Association for primary and secondary education in the United States [37]). In Germany, computing education standards for secondary schools have been proposed by the German Association for Informatics (Gesellschaft für Informatik) [7]. The standards bridge computing with Information-Communication-Technology and therefore can be aligned with the context-based approach “Informatics in context” discussed in the previous section. Therefore, we chose these standards as another framework for computing content choice.

The suggested German standards consist of two major competency areas. The first one is focused on five content specific competencies and subdivided into: information and data; algorithms; languages and automata; information systems; informatics, people, and society. The second area is focused on five process-specific competencies and subdivided into: modeling and implementing; arguing and evaluating; structuring and networking; communicating and cooperating; presenting and interpreting. Each subfield contains a detailed description of what students are expected to know and be able to accomplish by the end of a certain grade [7]. Since being introduced, the standards have been used to frame several context-based teaching units and digital artifacts like E-Mail [17], mobile phones or the internet exemplifying the related competency areas. For theoretical considerations, we were wondering whether a specific GIS can be used the same way to teach computing education with regards to the standards. For that matter, we compared each content- and process-specific competency described within the standards whether they are exemplified by GIS. We have found for each area potential examples how GIS could be used to exemplify the related computing content and process competency. As a same methodological approach, the CS principles by Denning or detailed definitions of Computational Thinking could be used as a framework to clarify relevant CS learning objectives.

IV. Teaching Computing in Context of GIS

In order to gain first insights whether our considerations for creating an educational design makes sense so far, we have created a new GIS course that was taught by co-author Otto and offered for graduate students of Geography Education at the University of Hamburg (starting in April and finishing in July 2016). In this section, we introduce the course details and first results of an ongoing evaluation.

With an emphasis on increasing student interest and motivation to study GIS and relevant CS concepts, we have focused on contextualization as discussed in the previous section on the German computing standards for deriving computing-related learning objectives. Hubwieser explicitly suggests pedagogy for secondary CS education while incorporating relevant training with related Information Technology [23] and, therefore, was another good model for creating single lessons especially those centered around modeling. We worked with QGIS, an Open Source GIS and ArcGIS Online, the cloud-based Web version of ArcGIS Desktop. The course was designed as a weekly classroom seminar with selected readings, practical assignments and a final project in a blended learning format attended by 18 students.

TABLE II. Computing related Learning Objectives based on the German CS Education Standards

Related to the standard Information and Data: • Understanding information processes in GIS • Using Graphical Representation forms (Vector and Raster) • Knowing and using different data types for spatial data
Related to the standard Algorithms: • Understanding the use of algorithms for spatial data analysis
Related to the standard Information Systems: • Organization and structure of GIS • Applying a specific GIS for a geographical problem
Related to the standard Modeling and Implementing: • Identifying objects, their attributes and values of a geographical problem • Analyzing spatial data and developing simple models
Related to the standard Presenting and Interpreting: • Presenting and interpreting diagrams, graphics and results created with GIS

A. Climate as a thematic Context for GIS

Following the context-based approach introduced in III.A, a meaningful context needs to be chosen that incorporates the relevant topics and works with GIS as a common thread during the whole teaching unit. For that matter, we have chosen climate change and climate modeling as a meaningful context with related regional and national climate phenomena (Hamburg and north of Germany), respectively [28]. This context is also an important topic for secondary Geography education, explicitly mentioned in the German Educational Standards of Geography [22] and therefore an additional incentive for Geography Education students.

The topics climate/climate change is describing and analyzing the interaction between the climate system and other ecosystems on Earth [34]. The main focus is on different climate elements and how changes in these affect the system on various geographic scales. Research in this field is of great importance due to the influence humans are assumed to have on the climate system [28]. In the investigation process, computing models are used to model and analyze the climate system and to predict future changes. These models require vast amounts of data in order to successfully model the climate system. Here, GIS is a widely used tool to gather, analyze, and visualize climate data. Therefore, climate change and climate modeling is an ideal context for introducing how GIS can be meaningfully used in geographical work and how computing is supporting it.

B. Deriving Computing Concepts

Following the German CS Education standards, we derived computing-related learning objectives for our GIS course, which are summarized in TABLE II. Building on these objectives, the following GIS-related CS content was presented in the course:

- Difference between Geographical Information and digital data
- Graphical representation forms (Vector/Raster)
- Data types and GIS-related data models
- Data management and manipulation
- Basic analytical data operations in GIS
- Voronoi Polygons and Inverse Distance Weighted interpolation
- Essential components of GIS
- Database organization
- Query operations in SQL: principles and simple select-operations with AND/OR operators

C. Course Syllabus and Teaching Experiences

Creating a course syllabus, a major challenge was the ordering and breadth of the three course topics, i.e., Climate/Climate Change, GIS, and CS. Here, we made three decisions: First, we decided to start with the context in order to motivate GIS activities and the study of related computing content following afterwards. Second, we decided to follow the idea of the spiral curriculum [9] and arranged the course content around a first part focusing on Climate and a second part focusing on Climate Change. Third, we decided to present and discuss CS topics but request specific computing-related assignments only in context of QGIS activities. The last decision was made because we had only little understanding of students cognitive and motivational prerequisite regarding CS. Given the overall negative image CS has in general among most non-CS students, we paid attention not to overwhelm students and kept a good balance between CS and context while spreading the word that a computing-oriented, context-based GIS course is interesting and worth to be attended for future tests.

Starting with temperature and precipitation, two important climate elements, we introduced the difference between geographical information and digital data and how they can be used in GIS in general and with QGIS in detail. The students learned how to transform tabular data into point vector data and how to manage and visualize the data using classification methods. As temperature and precipitation data are continuous and only weather station locations could be visualized in point data, the next step was to introduce the students to analysis options that would transform point data into a continuous map showing the average annual temperature or precipitation for a certain region. The algorithms used for this transformation were Voronoi Polygons and Inverse Distance Weighted interpolation. We introduced and explained both algorithms in addition to showing how they can be applied in QGIS. Since most students encountered the concept of an algorithm for the first time in their life, we did not provide additional assignments for working with the chosen algorithms outside GIS in order to avoid exhausting student motivation. In this first part, the students learned the workflow on how to obtain data on climate elements and how to transform, manage and visualize this data to create a continuous map in GIS. All these tasks were performed on different geographic scales showing students how similar tasks help them to obtain different data on a global, continental, regional or local level. In between, we introduced database organization and relevant CS content following Hubwieser (2012) but using climate related examples and GIS, i.e., data structures, representation of information and processes, queries and reports, and first SQL-statements [23].

In the second part of the course, students were introduced to the topic of climate change and how to model and analyze related phenomena using GIS, e.g., the analysis of satellite imagery in the context of melting glaciers and rising sea levels, creation of flood models to predict consequences of climate change, or visualization of statistical data on a national level regarding climate change. For that reason, various climate models and data sources were introduced, and different ways of comparing historic or current data were presented, for example the Raster Calculator. Related to climate change, the same relevant CS topics were discussed again, especially data modeling with relational databases as suggested by [23].

The course finished with a final project where students worked on a problem of their own interest, but one related to climate change and presented their project results to the group. For that matter, they were asked to retrieve, transform, analyze and visualize relevant digital data and use it to discuss and explain a phenomenon of climate change.

D. Insights and first results of Course Implementation

Discussing the idea of including computing related topics within a GIS course for pre-service Geography teachers, we were not sure if we will find enough students willing and interested to attend the course – especially since they were not much engaged in GIS during their undergraduate GIS courses. Therefore, we were very pleased to see 18 students not just starting but also attending the complete course while providing us with very good feedback that they liked it and that they were learning interesting aspects of GIS and computing they had never heard or thought about before. Within the course, students asked questions of understanding regarding climate change, the use of specific GIS functions, as well as the introduced CS topics, indicating that they were engaged with all different course components. Therefore, our overall first impression is that this first attempt worked very well, for the students and that it makes sense to further use contextualization as a pedagogical approach and secondary computing education standards as a framework for our design.

By the end of the course, we also collected data for a first evaluation. We are still in the process of analyzing this data but first insights confirm students' general satisfaction with the course. We only received one major critic: Students complained that we didn't address pedagogical content knowledge of GIS and potential approaches of secondary GIS education. Since it was never intended to include these topics, we take this feedback as a strong indicator for success: If pre-service Geography teachers want to know how they could use GIS for their own teaching, we have fully succeeded with this first teaching approach of our concept. Surprisingly, students judged climate and climate change to be far less interesting and relevant to learn about than we expected and also than their interest for the mentioned CS topics. Climate/Climate Change could be simply less interesting for students than other thematic contexts from Geography. Also, our low-key approach regarding computing topics might have created these positive result. Augmenting CS Education within such a course, we expected students to be more critical here. Also, playing with geographical topics, using another context will reveal how strong contextualization impacts student motivation. In sum, it seems that students felt well motivated to all required course activates and topics. Since we don't have a comparison of student performance in the same course not using a thematic context, future evaluations will require a specific research design to capture how strong context is really impacting student motivation.

V. Conclusion

In this paper, we have discussed CS Education in context of non-CS disciplines and presented a context-based approach with GIS for pre-service Geography students enabling them to tap into the full potential of Information Technology in the context of their discipline. Several challenges were met like questions regarding choosing adequate CS topics, learner-centered pedagogy, and their combination within GIS use-cases and discipline related tasks from Geography. One particular challenge of applying the approach outside regular CS courses is creating the awareness and relevance for CS Education among non-CS students as well as involved faculty of another department. Within the field of Geography, GIS courses tend to be focused on training how to use a specific GIS rather than studying the principles of this Information Technology from a geographical and computational perspective. Introducing a relevant context and related CS topics, the challenge is to incorporate these into the course without dominating it and we have provided first suggestions for that matter. As a next step, we are refining the overall design of the course and plan another testing during the summer semester 2017. With this transdisciplinary research project, we contribute in connecting CS Education to the field of Geography reaching out to students that usually are not exposed to CS Education.

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