INTEGRATING 'EDUCATION FOR SUSTAINABLE DEVELOPMENT' IN STATISTICS CLASSES: VISUAL ANALYSIS OF SOCIAL AND ECONOMIC DATA WITH GAPMINDER

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Sustainable development goals (SDGs) address various aspects of future human development such as poverty, pollution, or climate change. Education for Sustainable Development (ESD) seeks to encourage students to actively participate and consider these issues in sustainable development. Following design-based research approaches, our study aims to identify opportunities for integrating ESD into statistics education. We describe the main features of an ESD-integrated learning trajectory for middle school students exploring sets of ESD related data visually with the software Gapminder. The outcomes of our study suggest that (1) Students' engagement in forming statistical models of various countries' sustainable development developed their abilities to generate statistical questions (2) Their intuitive knowledge of statistical concepts was further formalized during their subsequent analyses.

THEORETICAL BACKGROUND

In understanding civic statistics, Nicholson et al. (2018) emphasise the importance of teaching statistical literacy in school education to prepare young people for responsible citizenship. Accordingly, "[…] citizens need to understand statistics about past trends, present situations, and possible future changes in diverse areas of importance to society such as demographics, employment, wages, […] and other domains" (p. 2). Further curricular goals of statistics education are often related to the understanding of issues around statistical investigations with real data (Biehler et al., 2018). In their framework of *statistical literacy in the Open Data era*, Prodromou and Dunne (2017) describe students' conceptions of statistics as instruments of forming models relating to their "ability to use statistical models to describe a wide range of phenomena in our world and quantify an aspect of these phenomena" (p. 20). With the *cycle of inquiry and visual analysis*, Prodromou (2014) presents a model for students' explorations and analyses of data particularly through visual methods in 5 non-linear, repeating steps. Analysing data visually, students are a) identifying the task, b) foraging for data, c) visualizing data, d) understanding patterns through interacting with data visualizations, and e) rating the results regarding the task. Considering processes of generating statistical questions being highly important for the first steps of such statistical investigations (Biehler et al., 2018), "the first challenge is to transform that general question about the real world into a statistical one" (Konold & Higgins, 2003, p. 195). Examining opportunities to implement such investigative processes in introductory statistics classes, Andre et al. (2019) describe students' intuitive perceptions (Fischbein, 1987) of statistical concepts during visual data analysis and conclude that "basic ideas, such as models of regression, centre or variability, tend to be intuitively accessible for students" (Andre et al., p. 7). Combining these issues, the discerning use of real data in enquiry- and problem-based as well as technology-rich statistics classes is a great opportunity to integrate topics highly relevant for students into statistics education.

Elkington (1998) defined sustainability as respectful interaction between economic, social, and environmental aspects of development. Other frameworks emphasise the well-being of each citizen, i.e., a good social foundation, while society is protecting the Earth's life-supporting systems, i.e., society is respecting the Earth's ecological ceiling. Raworth (2017) used the seventeen sustainable development goals (United Nations, 2015) to define a *Doughnut model* for sustainable development: "Between these two sets of boundaries [the ecological ceiling and the social foundation] lies an ecologically safe and socially just space in which all of humanity has the chance to thrive" (Raworth, 2017, p. 1). O'Neill et al. (2018) adopted the model such that all utilized indicators have officially recognized, provable threshold and limits, making it possible to publish national doughnuts for every country (see figure 1, right). Thus, regarding the doughnut model as a tool to analyse countries' sustainable development, beneficial achievements are described in various facets through filled

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sections of the inner circle, i.e., fulfilling various social thresholds, without an overshoot in the outer sections, i.e., the ecological ceiling is respected (see figure 1, left). The *doughnut model* is especially suitable to describe sustainable development because it considers dependencies between the issues and offers therefore opportunities to easily understand the concept of sustainable development.

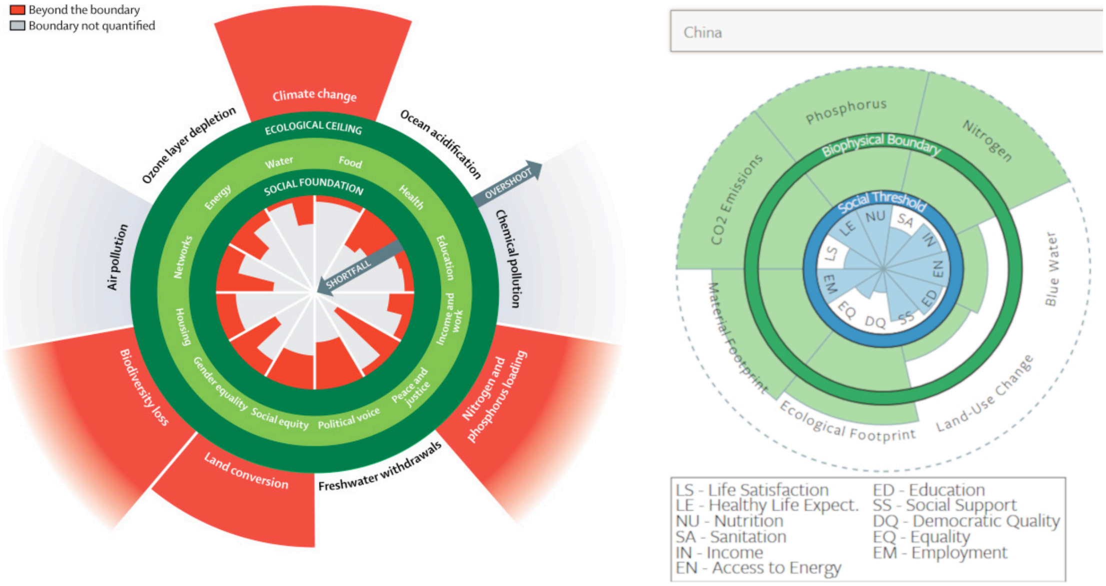

Figure 1: Doughnut model (Raworth, 2017) and national Doughnut for China (O'Neill et al., 2018)

Despite the importance of teaching sustainable development in schools, teachers encounter major problems integrating ESD into their lessons (Taylor et al., 2019). As sustainability is a relatively new topic in school education, just in the past decade, researchers have been defining curricular goals and competences needed for students to become responsible citizens. With the aim to close the knowledge-action gap, ESD is concerned to support students in developing competences towards actively participating in sustainable development. Therefore, students should become aware of problems associated with sustainability as well as acquiring skills in solving problems related to these issues (deHaan, 2010). Analysing different aspects and various prior definitions of ESD related competences, Rieckmann (2018) deduced eight key competences from this previous work which are relevant to statistics education, too. For example, the *systems thinking competency* is defined as "the ability to recognize and understand relationships, to analyse complex systems, to perceive the ways in which systems are embedded within different domains and different scales, and to deal with uncertainty" (Rieckmann, 2018, p. 44). Furthermore, the *anticipatory competency*, the *critical thinking competency*, and the *self-awareness competency* are partly linked to statistical ideas such as estimating trends, covariational relationships and issues of causality, or comparing groups.

METHODS AND IMPLEMENTATION

Based on the theoretical background, we designed an interdisciplinary learning trajectory, where middle school students access their intuitive knowledge of statistics to carry out their own investigations on sustainable development of single countries through applying the cycle of inquiry and visual analysis (Prodromou, 2014) of social, environmental and economic data with the software Gapminder. An applet of the *doughnut model* was used to visually demonstrate sustainable development of these countries (see figure 2). Besides addressing ESD competences and knowledge of sustainable development, we aimed to trigger students' intuitions on various statistical concepts as a starting point for further learning processes when students formalize their informal knowledge of the concepts addressed.

This study is embedded in a larger research project following design-based research approaches (Bakker, 2018). The design of our learning trajectory and according design-principles are iteratively enhanced with the single studies of this project. The study presented in this paper concerns the questions: (1) How can students be engaged with statistical modelling of sustainable development issues? and (2) How are students' developments of ESD competences and the process of statistical investigations by visual methods related to each other? Various records of the implementation of this learning trajectory in two grade 8 classes of a middle school form the basis for this report. 45 students participated in this study with a duration of 12 lessons, 50 minutes each, spread over two weeks. According to their teachers, mathematical abilities of students in both classes were wide-spread from low-achieving to high-achieving and their pre-knowledge of statistics from earlier classes was limited to calculating ratios and arithmetic means.

Two inhomogeneous groups of three students each were chosen by their teachers to be recorded during their statistical analyses. We qualitatively analysed the videos recorded during the lessons and all students' solutions of worksheets and tasks with the software MAXQDA. Conducting an evaluative assertion analysis (Kuckartz, 2012), students' performance relating to the expected outcome of solving the tasks was rated as high, middle, or low achieving (Bakker, 2018), and students' statements during their investigations were coded according to the eight *key sustainability competencies* (Rieckmann, 2018) and the *central statistical ideas* (Garfield & Ben-Zvi, 2008) as well as to the stages of the *cycle of inquiry and visual analysis* (Prodromou, 2014).

In the first phase of the learning trajectory, students reflected in groups on their own living circumstances regarding their social needs and their attitudes that affect the environment. With the outcomes of the discussions, students' individual *doughnut models* (Raworth, 2017) were created showing their key issues. A brief introduction to the Gapminder tools completed the preliminary lessons. Based on these conceptions of the *doughnut model*, during the second phase, further described in this paper, students worked in groups of three, and statistically analysed different countries' sustainable development data. Finally, in the third phase, students created infographic posters and wrote statistical stories to display outcomes of their investigations.

In the second phase, all investigations on a chosen country were guided by worksheet. Thus, students were advised (1) to choose a variable from a list of variables available in Gapminder, which they believed was relevant for sustainability issues. (2) They related the chosen variables to the ecological ceiling or to the social foundation and (3) explored that variable by creating various visualisations with the Gapminder software. (4) They then rated the value of the variable according to its impact on the country's sustainable development. (5) Finally, students transferred their results of this process into a GeoGebra applet of the doughnut model, adjusting sliders in the applet (see figure 2). The five steps were repeated several times to receive a complete doughnut graphics of the chosen country under examination. For each variable, students had to briefly note down their reasoning of the rating process on their worksheet. According to officially recognised boundaries and thresholds, for some variables coloured scales were provided for rating the data values regarding sustainable development (see figure 2, bottom) in order to support low-achieving students to participate in the process.

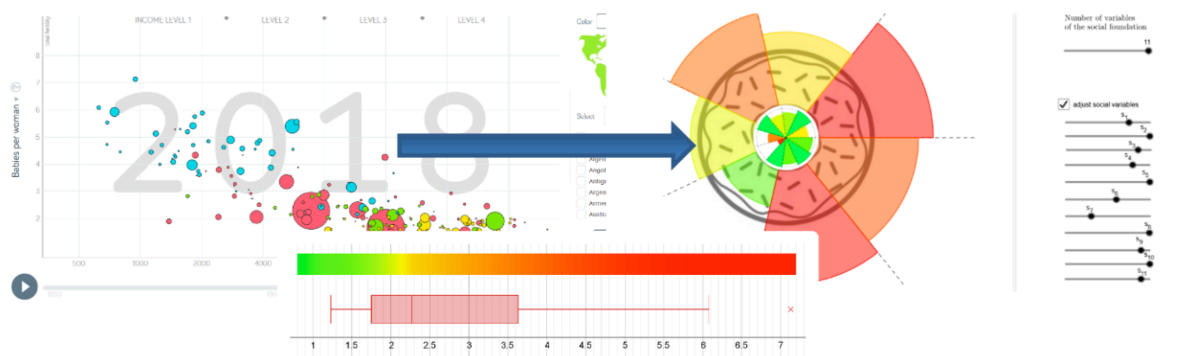

Figure 2: Visualisation of the process transferring information concerning the number of *babies per woman* from Gapminder to the GeoGebra applet.

The applet and other applied materials are provided as Open Educational Resources in English language (https://www.geogebra.org/m/gg8hgavw). An in-depth description of the entire learning trajectory in German language can be found in Andre et al. (2019).

RESULTS AND DISCUSSION

In this section, we will firstly analyse our findings related to students' approaches to statistically modelling single countries' performance in sustainable development. Secondly, we will outline how the modelling task enhanced students' abilities in generating statistical questions and, finally, we will describe relations between students' analysis of covariational relationships and their development of *key sustainability competencies*.

As students built their own statistical models to describe sustainable development in the first phase of the learning trajectory, their own *doughnut model* formed a predefined structure for students' analyses of ESD related variables in the second phase. Guided by worksheets, the steps of students' investigations on single variables were based on the *cycle of inquiry and visual analysis* (Prodromou, 2014). Thus, students (1) chose a variable, (2) related the variable to the ecological ceiling or the social foundation, (3) visualised the variable with the Gapminder software, (4) determined the data value of the analysed country in visualisations, and (5) interpreted this value regarding sustainability issues. The steps (2)-(5) did not build a linear process but were often mixed by the students. Regarding the variables chosen by students, *CO_2-Emissions* was used by each group. To justify their choice, one student stated that "CO_2-Emissions are highly dangerous for the climate" (Student #9a), another student declared that "it is astonishing how far, too high emissions of rich countries are" (Student #10b). Other variables of interest for pupils were *cell phones use*, *access to electricity*, *babies per woman*, *life expectancy* or *threatened species*. When students visualised their chosen variables, in almost every case they used Gapminder's *bubble chart*, i.e., a scatterplot, as a first step to determine the needed values. To rate these values to sustainable development, some groups additionally used *ranks* or *trends* graphics. Considering students' interpretations of scatterplot graphics, the idea of covariation could often be found in their considerations, especially referring to income and pollution/*CO_2-Emmisions* or when working with the variable *babies per woman*, where, for example, student #4a stated astonished: "Living in a rich country, one should have more children and less children in a poor country. But it is the other way around." After having analysed some variables, students #1c stated "We must find something good; the country performs so bad until now."

Comparing students' performance in solving the tasks and the steps of the cycle of inquiry and visual analysis, we concluded that the use of data meaningful to students highly influenced all steps of their investigations. Analysing variables such as the *Gini-index*, which had been unknown to the students before it was introduced and explained, students struggled especially in the step of interpreting the value regarding sustainability issues. Moreover, we found that students did not have any problems to interpret negative relationships when analysing, for example, the variable *babies per woman*, and they continuously switched their thinking levels between data and real-world perspectives. Whereas these switching processes were already described by Ben-Zvi and Aridor-Berger (2016), the correct, intuitive interpretation of negative covariational relationships (e.g., Biehler et al., 2018) is an exception to researchers' earlier results. The last-mentioned statement of student #1c on the manipulating choice of variables is especially worth mentioning because this statement initialised discussions regarding the idea of sampling linked to the statistical modelling process. Finally, at the end of the learning trajectory, all students were able to correctly interpret a *doughnut model* of a fictive country and they related the concept of the *doughnut model* to their own lives, since it formed a generalisable structure for students' reasoning about possible enhancements regarding their personal sustainability issues.

Analysing students' investigations, we found, too that the task of statistically modelling a phenomenon in various aspects supported students' development of their understanding of generating statistical questions. Carrying out the task, students chose a variable, initially visualised this variable in Gapminder's scatterplot, and determined its value. Still, the general question behind the task was: "How does the country perform regarding sustainable development?" Students did not pose any statistical questions during these first steps. Since the subsequent step of the task was to interpret a specific value regarding sustainable development, students generated questions such as "What does this specific value mean for sustainability issues?". Then, either students interpreted the value according to the scales provided to assist low-achieving students in their interpretations, or they further tried to interpret the value for themselves. In the second case, students started to pose statistical questions, e.g., on the range of the dataset, trends in covariational relationships, the position of the specific data values relating to the other values, or differences between rich and poor countries. Thus, students compared values of a country with the centre of the data set, which they built intuitively based on the *bubble chart* or *ranks* graphics, stating "because the bubble is in the middle" (groups #2a, #6b using scatterplots) or "the value is in the lower middle" (group #3b using the graphic *ranks*). Students also mentioned the idea of variability and spread, e.g., stating "People who live in the same country, don't earn the same" (student #15a) or "[the variable] babies per woman is interesting, because in some countries women have many babies and in other countries they have much less [babies]" (student #17a). From these observations we could conclude that, besides the importance of contexts meaningful to students, the need for interpreting the data was key for students to generate statistical questions, especially, regarding adjusting processes between various kinds of visualisations and according statistical questions on the one hand, and possible, intuitive interpretations of the visualisations on the other hand. Thus, earlier findings of students' switching between data and real-world perspectives (Ben-Zvi & Aridor-Berger, 2016) and a non-linear arrangement of the steps of the *cycle of inquiry and visual analyses* (Prodromou, 2014) can be explained more deeply by considering the process of generating statistical questions triggered through the need for interpreting visualisations.

Concerning the question of relations between students' acquisition of ESD competences and processes of statistical investigations, we focused on students' intuitive interpretations of covariational relationships. As each student was working with at least seven scatterplots showing income on the horizontal axis and ESD relevant data on the vertical axis, we found numerous intuitive statements of students regarding the idea of covariation between those numerical variables in our recordings. Focussing on students' various intuitive statistical concepts, the setting of our study did not allow us to clearly rate each student's reasoning about covariation according to the SOLO Taxonomy (e.g., Biehler et al., 2018). Therefore, we did not code students' statements regarding that taxonomy. A later analysis suggested that some students' statements indicate a *multistructural* level of reasoning whereas some students remained on the *unistructural* level, concluding their reasoning with sentences from the style "the more … the better …". More general statements concerning the *doughnut model* given in the final lessons, such as "everything we get for the social foundation has ecological costs" (student #3b) or "There are ecological and social factors. When our ecology is not healthy, we must deal with individual health problems." (student #6a), might also be interpreted as generalization of the idea of covariation and a *multistructural* level of thinking, gained by students' previous engagement with various scatterplots. Furthermore, these statements also show their *systems thinking competency* recognizing multiple dependencies between social and ecological issues. Thus, we concluded that enhancements of students' *systems thinking competency* can be supported by activities raising students' thinking levels regarding covariational relationships from *unistructural* to *multistructural* and further to *relational*.

CONCLUSIONS

Our designed learning trajectory offered opportunities for students to engage in statistically modelling the phenomenon of sustainability. Identifying various measurable aspects of this real-world problem, students created concepts of sustainability for themselves forming a structure for their subsequent data investigations. Relating data values to sustainability issues contributed to the process of generating statistical questions. Students' intuitive perceptions of statistical concepts through various visualisations, particularly of the concept of covariation presented in scatterplots, were a starting point for further learning processes. Therefore, we concluded that students can be supported in developing a conception of statistics as an instrument of forming models through such interdisciplinary learning environments addressing real-world issues which are meaningful to students. Moreover, students' intuitive interpretations of data visualisations in a problem-based and student-centred learning environment is a basis for students' acquisition of informal knowledge of various statistical concepts to further support students in adjusting their informal knowledge to the formal concepts. The results of this study will be used to re-design the learning trajectory focussing on opportunities to increase students' levels of thinking regarding their covariational reasoning and to increasingly support students to develop an understanding of statistical modelling processes.

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