

# PROMOTING SUSTAINABILITY LITERACY IN SCIENCE EDUCATION

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## Abstract

In this paper, we report about the promotion of Sustainability Literacy (SL) within the master study programme of ongoing biology teachers at the University of Bremen. Starting from a literature recherche on the epistemological aspects of SL we examine different scenarios of complex and controversial socio-scientific issues in the context of biodiversity change and climate change. We argue for a complexity of content, context, and methods in understanding of current problems in the field of Education for Sustainable Development (ESD).

Focusing on a model of project learning which includes subject knowledge, dialogical and reflective approaches we develop a complex seminar programme (one semester, 180 hours work load) to different future challenges such as „Future change: Woods and Forests“, and „Future change: Agriculture“. We call the programme „INQUIRE for Teacher Students“ (Inquiry based Teacher Education for a Sustainable Future) course.

The programme comprises three modules:

In the first module (Information) subject knowledge in regard to biodiversity loss and climate change, climate and ice, and agriculture/forest management and soil is promoted via expert talks, experiments, excursions and discussions. In addition, models to diagnose and promote the ESD competences for system thinking, valuing and decision making are discussed. The participants learn to know new didactical methods of ESD such as role plays, future conferences, inquiry based science education (IBSE), Educational Escape Games and digital tools such as Reflectorys.

In the second module (Didactics) information about Agenda 2030, the curricular orientation frame for its implementation and connections of ESD and the current local school curricula is given. Based on these information the teacher students develop in teams (each team with three to four participants) teaching and learning materials for school students of the upper secondary level with the goal to promote and evaluate ESD competences.

In the third module (Conduction and Evaluation) the teacher students conduct their self-developed teaching and learning material. Therefore, they invite the school classes to come to the University Bremen and participate in the 4-6 hours lasting ESD projects.

During the last two years we conduct the INQUIRE programme with 63 teacher students. Our focus on research comprises aspects of

- Promotion of the participants' ESD competences subject thinking, valuing and decision making and acting for sustainable development;
- The participants' Sustainability Literacy (SL) at the beginning and at the end of the seminar.

The data are based on written team portfolios (teaching and learning materials, guidelines for teachers, team reflections), and individual reflections about the own professional development. In addition, the developed teaching and learning materials are analysed. The analyses are based on qualitative methods according to the paradigm of the Qualitative Content Analysis.

The findings demonstrate a heterogeneous picture about the ESD competences of the participants: especially sub dimensions of system thinking (system organisation, system development) are promoted. In addition, the diagnose competences regarding the ESD dimensions are promoted. The Sustainability Literacy of the participants in general in a medium level. We could report especially a significant impact of the INQUIRE course on systemic thinking and futures thinking.

Keywords: sustainability, literacy, science education, higher education, biology.

## 1 INTRODUCTION

The problems associated with biodiversity loss and climate change are one of the major challenges of the 21<sup>st</sup> century. They are characterized by their high complexity. Understanding this complexity requires to think about these issues from multiple perspectives. System thinking is essential for increasing the ability to understand the challenges facing our society today, to develop solutions, and to take actions as global citizens [1]. The ability to think in terms of systems is considered a higher-order thinking skill, and includes examining, evaluating, and inventing, which include more than just the recall of facts [2]. System thinking requires an individual to have an understanding and recognition of concepts and principles about a particular domain represented by dynamic phenomena and their relationships [3].

Education for Sustainable Development (ESD), which has represented a cross-disciplinary educational goal since Rio de Janeiro in 1992, aims to encourage students' competencies and skills required for sustainable social development and planning [4]. This is motivated by the belief that students will only be able to participate in sustainable development once they understand the complex and global context as an interconnecting system [5].

To promote system competences, the so-called "syndrome approach" developed by the German Advisory Council on Global Change (WBGU) is a promising way. This is a multidisciplinary analytic tool for identifying unsustainable developments and environmental problems in earth systems by considering them as disease patterns, the so-called "syndromes" of global change [6]. The syndrome approach aims in representing, reducing and returning complex environmental problems to distinct comprehensible relationships [7], [8], [9]. It focuses on the ecological, socio-cultural, and economic dimensions and their interactions in order to foster sustainable development.

Although the new biology and geography curricula reforms have made explicit the call for teaching system thinking in the science classroom the promotion of sustainability literacy in appropriate training programs for prospective biology teachers are a research desideratum.

Are teacher candidates well prepared to promote pupils' system competences?

What is sustainability education and how to promote the sustainability literate teacher?

The following study examines the impact of the practical course "INQUIRE for teacher students" on teacher candidates' system thinking based on the syndrome approach, and their sustainability literacy in regard of teaching a complex environmental problem.

## 2 SUSTAINABILITY LITERACY IN TEACHER EDUCATION

### 2.1 Sustainability and Education

Sustainability describes a development which does not endanger the intergenerational viability of human welfare in terms of environmental, social and economic systems. Based on the United Nations Brundtland Report on Environment and Development, sustainable development "*is the type of development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" [10, p.41]. In the three elements of sustainable development, that is social, economic and environmental, social or human welfare has been considered above environmental or ecological development [11].

According to the United Nations Division for Sustainable Development Agenda 21, *education* has a crucial role in building a society's capacity for changes [12], especially in the way society prepares itself to address environmental issues. Education for sustainability transforms minds as it "*equip[s] people with the skills necessary to be leaders and engagers in the process towards sustainability*" [12, p. 164]. The importance of education for finding sustainable solutions to global issues was affirmed at the 2009 UNESCO World conference on education for sustainable development, when it committed to: education that empowers people for change. Such education should be of a quality that provides the values, knowledge, skills and competencies for sustainable living and participation in society [13].

Sustainability education therefore does more than environmental education might do in terms of providing knowledge about sustainability; it makes learners aware of their impact on the environment and encourages them to find means to minimize it. Thus education for sustainability is not only about providing knowledge of the issues of sustainability for bringing "*social change towards sustainable development*" [12, p. 4]. Hence, a capacity to reflect and think critically which plays a major part in bringing such behavioral changes in learners is at the heart of sustainability education. Other key

elements of good practice in education for sustainability are imagining a better future, participation in decision-making, partnerships and systemic thinking [12]. Building capacity for developing these attributes in students is at the core of education for sustainability in both formal and informal learning settings.

## 2.2 The sustainability literate teacher

*Our Common Future*, the report of the World Commission on Environment and Development [10] states that “the world’s teacher has a crucial part to play in helping in bringing about the changes in attitudes, social values, and in aspirations related to and required for the longevity of our planet” [10, p. 8]. Furthermore, *Our Common Future* highlights that these changes will play out in the public sector through deliberate education and public education. Teacher education programs must answer this call by preparing educators both as citizens and future leaders to enter a changing world where problems and solutions related to sustainability are seen as essential [14].

What are the competences a teacher should gather? The vision is to build a capacity for teachers to be able to approach the broad and complex nature of sustainability, the problem-oriented, solution-driven nature of sustainability, and, how sustainability connects to them as both citizens and classroom teachers. As a possible solution to reach this goal Warren et al [15] developed the complex *Sustainability Education Framework for Teachers* (SEFT). The goal is to acquire “sustainability literacy”, various abilities and subsequent actions such as problem-solving and decision-making [16]. Once teachers gain sustainability literacy they become empowered to approach society with a critical lens, teach sustainability topics and ways of thinking to their students, make informed decisions, contribute to rethinking interpersonal, intra-personal, intergroup and intra-group concepts of society and the environment [15], [16].

SEFT embraces four ways of thinking – futures, values, systems, and strategic thinking – which are strongly interconnected. They build a complex framework for analysing problems through a networked approach, offer organizing principles for examine and considering sustainable solutions, and provide the opportunity of self-reflection and independent enquiry by considering and learning real world foci [15].

*Futures Thinking* - also known as anticipatory thinking, foresighted thinking, or trans-generational thinking - is the ability to think systematically about the future and future generations. In seeking sustainable solutions, stakeholders, policy makers, and citizens need to consider how past decisions led us to the crises we face today.

*Values Thinking* is also known as values-focused thinking, orientation thinking/knowledge, and/or ethical thinking. Because sustainability is a field that is problem-oriented and solution driven, potential solutions require the consideration of values.

*Systems Thinking* considers cascading effects, system variables, positivity and negative feedback loops. This recognizes the physical limits of earth systems, as well as appreciating the endless opportunities for creative innovation both at the global and local levels.

*Strategic Thinking* considers possible solutions under a given set of assumptions, articulating potential alternative solutions, and challenging existing assumptions and alternatives, potentially leading to new solutions that may be more appropriate.

According to Warren et al [15], these four ways of thinking are interconnected, bi-directional, and reflexive in a manner that allows them to be used synchronously or singularly to address sustainability challenges.

## 3 INTERVENTION

“INQUIRE for Teacher Students” is a pre-service practical course in the study program Master of Education Biology. It is an elective course for biology teacher students at the University of Bremen (Elster, 2013). It is offered in the winter semester and comprises 180 hours (6 Credit Points).

The program INQUIRE for Teacher Students is based on results of the European project INQUIRE - Inquiry-based teacher training for a sustainable future [17]. Biology educators, scientists, teacher students and teachers work together in a Community of Practice. The goal is to raise the awareness of the biodiversity by developing inquiry-based teacher units in student relevant motivational contexts. The content of these teaching units is about the interconnection of biodiversity loss and climate change.

The program is based on a broad understanding of Inquiry-Based Science Education (IBSE). We define scientific inquiry is a multifaceted activity that involves making observations; posing questions;

examining books and other sources of information to see what is already understood; planning investigations; reviewing what is already known in the light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations and predictions, and communicating the results [18]. Summarized, inquiry based learning is not about memorizing facts – it is about working with living organisms, observing natural phenomena, formulating questions, linking evidence to explanations and finding appropriate solutions to explain observations and address questions and problems. There may be simple tasks or complex undertakings but they will always lead to learners experiencing the excitement of solving a question or problem on their own, usually as part of a team [17], [18].

The INQUIRE for Teacher Students courses comprises three modules:

Module 1. The teacher students worked in teams and investigated the scientific background in regard to a ESD problem (e.g. Future perspective: climate change and forests; Future perspective: climate change and agriculture) by conducting excursions, and testing lab experiments supported by scientists, science educators, and teachers. To gather information about the socio-cultural background, the economic issues (e.g. tourism) and the historical and political dimensions, the teacher students interviewed the local inhabitants and visited museums.

Module 2. Supported by the science educators the teacher students conducted IBSE activities within their teams, promoted their own system thinking based on the syndrome approach and developed the complex simulation games or reflectorys for the school classes. The process of the development of the classroom interventions required agreements on the working process, shared goals of the participants, as well as a critical rethinking of one's own practice.

Module 3. In the next step the teacher students invited their school classes to conduct their simulation games or reflectorys. They evaluated the pupils' learning outcome and their own increase of knowledge and interest in regarding system thinking and IBSE. In addition, the teacher students reflected on the own professional development and sustainability literacy. The results of the evaluation were presented in a final project presentation.

During the whole project a meta-evaluation about teacher students' system learning and professional development was conducted with a mixed-method approach [8], [9].

## 4 RESEARCH QUESTIONS

During the last two years we conduct the INQUIRE programme with 63 teacher students. Our focus on research comprises aspects of

- Promotion of the participants' ESD competences subject thinking, valuing and decision making and acting for sustainable development;
- The participants' Sustainability Literacy (SL) at the beginning and at the end of the seminar.

## 5 METHODOLOGY

The data on ESD are based on written team portfolios (teaching and learning materials, guidelines for teachers, team reflections), and individual reflections about the own professional development. In addition, the developed teaching and learning materials are analysed. The analyses are based on qualitative methods according to the paradigm of the Qualitative Content Analysis based on Mayring [26]. This allows the building of deductive and inductive categories. The inter-rater reliability is determined by the Cohen's-Kappa-coefficient (in average 0,85κ).

Aggregate scores are calculated for the subject knowledge in respect to biodiversity, climate change, and the interconnection of biodiversity loss and climate change, and the PCK facets knowledge about didactical strategies, methodological knowledge, and assessment of pupils' competences.

For the analysis of system thinking the students developed syndrome networks in groups. The syndrome networks are analyzed according to their basal structure [19], the scope and the quantitative interconnectedness [20], and qualitatively with the relation scoring method [21]. The analysis of the basal structure allows insights in the cognitive thinking of the participants [21]. The way of connectedness (spoke is mono-causal, chain is linear, net is complex) correlates to the levels of the competence model of Rempfler et al. [22]. The structural complexity of the syndrome was additionally determined by means of three indices: The scope (U) according to Sommer [23], the interconnectedness index (VX) according to

Ossimitz [24], and the structure index (SX) according to Bollmann-Zuberbühler [25]. To evaluate the syndrome networks qualitatively the relational scoring method [21] was used.

The data on sustainability literacy are based on a short questionnaire based on Warren et al. [15]. We asked the students for their self-estimation in regard to the sustainability dimensions. We asked the teacher candidates about the self-estimation of their competences in respect to their strategic thinking, futures thinking, value thinking as well as system thinking by ticking a box within a 5-point-Likert scale.

## 6 RESULTS

### 6.1 ESD competences of teacher students

The analysis of ESD competences of the teacher students are based on aggregate scores calculated for the subject knowledge in respect to biodiversity, climate change, and the interconnection of biodiversity loss and climate change. The findings demonstrate that the subject knowledge about the consequences of climate change and its influence on the biodiversity was generally high. Many of the ramifications for global climate and the interconnection of ecosystems and ice masses (e.g. the influence of the gulf stream) could be identified in the given answers, as well as for economy and social issues.

To measure the impact of the INQUIRE course the students were invited to draw syndrome nets. In addition five questions were analyzed based on students' portfolios. The questions were about the subject knowledge about the endangerment of species, the attitudes towards protection initiatives, the attitudes towards human interventions in the ecosystem, and the possible strategic acting possibilities. The results demonstrated a high significant increase of syndrome specific subject knowledge. The analysis of the basic structure of the syndrome nets demonstrated the increase of complex structures (e.g. net structures). The quantitative analysis of the concept maps comprised the scope (U), the interconnectedness index (VX), and the structure index. The data show a high significant increase in the scope (all participating teams) and in the VX (65% of the participants).

The PCK facets knowledge about didactic strategies, methodological knowledge, and evaluation of pupils' learning were analysed based on the interventions conducted with pupils. The teacher students reported a high increase of their methodological knowledge (e.g. reflectory, mystery, future conference) and their didactic skills. Due of a lack of time the evaluation of pupils' learning was on a basic niveau.

### 6.2 Self-estimation of teacher students in regard of their Sustainability Literacy (SL)

The data about sustainability literacy are multifaceted and could not be reported within this presentation in detail. Therefore, we selected only two questions of the questionnaire survey. We asked the teacher candidates about the self-estimation of sustainability literacy in general (figure 1) and about the dimensions system thinking, value thinking, strategic thinking and futures thinking (figure 2). The participants were asked to tick a box within a 5-point-Likert scale (not informed – expert). The results demonstrate a change from mostly not informed and beginners to advanced (see figure 1). In regard to the SL dimensions the seminar has a significant impact on system thinking and futures thinking but no so fare on value thinking and strategic thinking (figure 2).

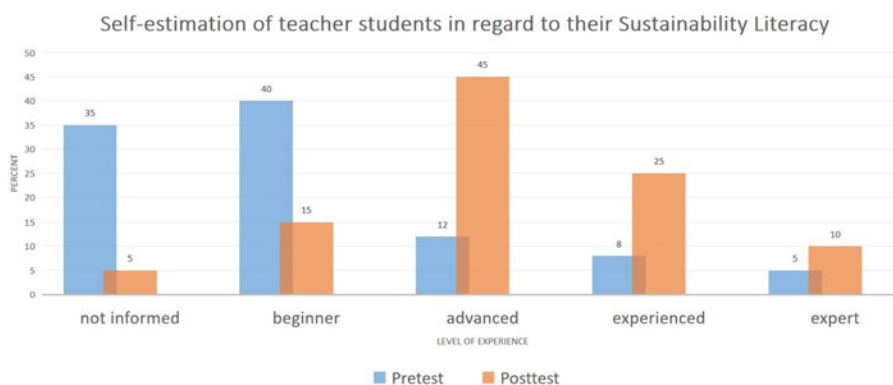


Figure 1. Self-estimation of teacher students in regard to their Sustainability Literacy (5pt-Likert-scale; n=63).

### Self-estimation of teacher students in regard to the SL dimensions

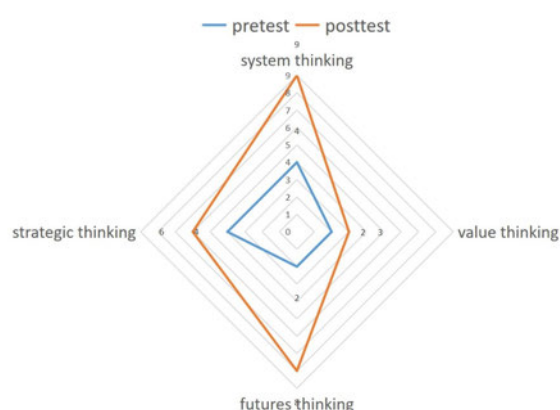


Figure 2. Self-estimation of teacher students in regard to their system thinking, value thinking, futures thinking and strategic thinking (10pt-scale; n=63)

## 7 CONCLUSIONS

The findings demonstrate a heterogen picture about the ESD competences of the participants: especially sub-dimensions of system thinking (system organisation, system development) and futures thinking are promoted whereas value thinking is at a basic level. The INQUIRE course offers a good possibility to promote the knowledge about complex methods to diagnose and promote ESD competences (e.g. through the working with syndrome nets). The participants learn to develop adequate material for the promotion of ESD dimensions and test and evaluate them in the classroom. To sum up, the INQUIRE course has been proven to be successful in the promotion of participants' teaching and learning of aspects of ESD as well as the improvement of the Sustainability Literacy of the participants in the dimensions system thinking and futures thinking.

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