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Open Educational Resources as a driver for manufacturing-related Education for Learning of Sustainable Development

Ina Roeder[a,*], Mustafa Severengiz[b], Rainer Stark[a], Günther Seliger[b]

[a]*Technische Universität Berlin, Industrial Information Technology, PTZ 4, Pascalstraße 8-9, 10587 Berlin, Germany*
[b]*Technische Universität Berlin, Assembly Technology and Factory Managenemt, PTZ 2, Pascalstraße 8-9, 10587 Berlin, Germany*

Abstract

Since the Massachusetts Institute of Technology (MIT) launched its OpenCourseWare program in 2002, the idea of an open and democratic education has spread rapidly all over the globe. Under the name of "Open Educational Resources" (OER), innumerable working sheets, curricular and teaching units have been developed and shared digitally under free commons licenses, connecting teachers and learners worldwide. Especially with regard to the UNESCO Education for Sustainable Development (ESD) Program, the concept has been allocated a pole position. However, challenges arise when it comes to matters of repository design, traceability, quality control and user acceptance. In this paper studies are presented that assess German and English manufacturing-related OER for sustainability education, targeting high school students, showing challenges and potentials of open education for sustainable manufacturing. It will be shown that classic schoolbooks leave inacceptable gaps when covering sustainable development by ignoring both, core issues of sustainable development and central didactic standards of Education for Sustainable Development such as competency-orientation. Although there are a number of German and English OER initiatives that could help close these gaps, they often do not make use of the full OER potential, as will be shown via quality assessment and a comparative analysis. Finally, an OER development process of the Collaborative Research Centre 1026 "Sustainable Manufacturing" will be described as a best practice example.

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Keywords: Open Educational Resources, Open Education, Education for Sustainable Development, Sustainable Manufacturing, Technology

* Corresponding author. Tel.: +49-30-39006-272; fax: +49 -30-3930246.
E-mail address: ina.roeder@tu-berlin.de

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1. Education for Sustainable Manufacturing and Open Educational Resources for massive learning

Since the "Agenda 21" as the central paper of the Rio Earth Summit by the United Nations in 1992, education is considered the basic requirement for sustainable development. Especially the young generation is capable of integrating new paradigms in their mindset as a foundation for making behavioral choices that lead to a more sustainable development path. Conducive competency-oriented pedagogical, didactic and institutional strategies [1] have been developed and discussed so broadly that "Education for Sustainable Development" (ESD) has turned into a technical term. However, in 2014, after more than a decade of intense campaigning work for sustainable development, only 43 % of Germans 18+ had some idea about what the term "sustainability" might mean [2]. While educational frameworks have been rewritten in Germany in order to integrate sustainable development into formal education, a survey with above-average students in 2014 showed that only about 50 % had any associations with the term [3]. Surprisingly, those associations were lacking any connection with the industrial sector, which, as a major stakeholder in many areas of human living, has a crucial role to play in sustainable development. The sector employs 24 % of the European workforce [4] and represents 25% of the final energy consumption in the EU 27 [5], while emitting 28.5% of the greenhouse gases [6].

The necessary implementation of *sustainable development* in all educational fields still faces significant challenges in Germany [7]. Especially the manufacturing-related aspects are so far being widely ignored in teaching, which is actually astonishing for a nation which is constantly one of the biggest players in terms of merchandise exports [8] and has an employment rate of around 24 % in the secondary sector [9]. What is true for a nation with an elaborate educational system and easy access to information can be considered to be equally true for the majority of scenarios of the global ESD challenge.

High expectations for educating populace worldwide have been raised by the concept of Open Educational Resources (OER) [10] and a great number of initiatives have risen ever since the Paris Declaration of the UNESCO 2012 World Open Educational Resources Congress (see e.g. [11]). There, OER were defined as "any type of educational materials in the public domain, or released with an open license, that allows users to legally and freely use, copy, adapt, and re-share" [12].

In Germany, teachers are free to choose their teaching materials as long as they cover the topics specified by their federal state's educational framework. OER allow for a wider variety of cases and examples than can be covered by a single textbook, and thereby encourage teachers to tailor their teaching units according to their students' interests or current debates. This is where topics such as sustainable manufacturing, which are widely neglected in education so far, can be brought to teachers' attention. The Public Awareness project of the Collaborative Research Centre (CRC) 1026 "Sustainable Manufacturing – Shaping Global Value Creation" has analysed the German educational frameworks as well as recent German schoolbooks and the German and international OER landscape regarding the field of sustainable manufacturing. Building on the findings, an OER teaching unit for the 9th and 10th grade has been developed.

2. Education for Sustainable Manufacturing through OER in Germany – an analysis

The federal measures for implementing sustainable development into formal education under the global program „21" and its German implementation „Agenda 21" have so far shown limited effects [3]. In-depth sample interviews with eight teachers from secondary education, led within our project, showed that they did not feel competent to teach sustainable development, let alone sustainable manufacturing. They felt a lack of fundamental understanding of sustainable development and teaching materials that would help them to overcome their knowledge deficiency in class. The generality of this notion becomes apparent in a study with teachers from schools that were implementing ESD programs under a local German program in 2015 [13]. Although all participants were already involved in ESD activities and had been offered qualification courses, 44 % said it is difficult to develop the necessary competencies for teaching ESD, and 51 % claimed that it is difficult to find adequate teaching materials. In the interviews of the Public Awareness project, teachers expressed their discontent with the way formal textbooks covered sustainability topics. As a resolve, some used costly extra materials that they purchased privately. Even those were said to disregard the role manufacturing plays for sustainable development. Hence, the authors decided to investigate the actual state

of commercial and also free teaching materials on manufacturing-related sustainability topics and to create OER using their expertise in the field of sustainable manufacturing, should gaps be identified.

2.1. Educational frameworks

In 2004 a resolution to integrate ESD into formal education passed the German parliament [14]. Three years later the Standing Conference of the Ministers of Education and Cultural Affairs published comprehensive guidelines for the federal states to rework their educational frameworks integrating ESD [15]. In 2012 the formal implementation was finished and the re-worked frameworks were to be put into practice. While the curricula propose that all teaching should be directed towards competency building for sustainable development, so-called *Gestaltungskompetenz*, it explicitly schedules sustainability mainly for the 9th and 10th grade in the context of globalization. In order to identify links to sustainable manufacturing in the compulsory teaching content, the educational frameworks for those grades were analyzed. Including the frameworks for all subjects of all high school types of the 16 federal states, the analyzed sample covered approx. 800 documents. Those were searched for content regarding aspects of sustainability in general and in the context of manufacturing and value creation.

The highest congruency was found for economy-oriented subjects such as "economy-occupation-technology". However, economy- and technology-oriented subjects are not mandatory and are taught at the minority of German schools; unlike geography, which is part of every German student's school vita and for which the educational framework showed the second best congruency. Except for two federal states, whose geography frameworks showed moderate consideration of the searched topics, all geography frameworks could easily be linked to sustainable manufacturing.

2.2. School book analysis

As a second step, the content of the 16 most recent German geography schoolbooks for the 9th and 10th grade was matched with the teaching content on sustainability prescribed by the educational frameworks. A listing of all explicitly named topics and the according subtopics was prepared for each educational framework. Thereafter the schoolbooks were searched for fitting content which was assessed using a three-point scale (0, 2, 4 points) according to the matching results. After adding the single results the high score for complete congruency with all frameworks was 182 points. The best ranking item scored 102 points, thus showed 56 % congruency. However, the average (arithmetic mean) was 44 points, e.g. 24 % congruency. This means that there is no schoolbook that would fulfill all frameworks' requirements, although there are some schoolbooks especially tailored for certain federal states that fulfill the specific requirements of that state. Still, there are also states whose frameworks are not met by any of the analyzed books.

The detailed content revision showed that only four out of those 16 books explain the concept of sustainable development to begin with. Also the majority fail to discuss the main challenge of sustainable development, its complexity through the conflictual potential of its three dimensions (see Figure 1). Furthermore, manufacturing and value creation receive little recognition as a vital element of sustainability strategies.

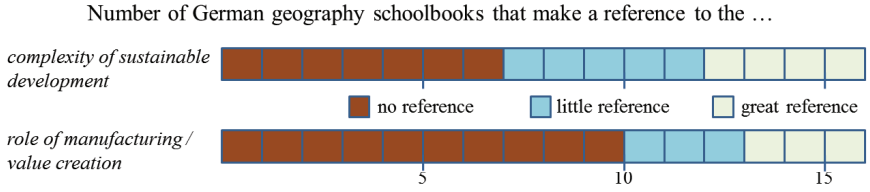

Figure 1. School book analysis regarding the representation of complexity of sustainable development and linkage to manufacturing

In the next step, the authors were inclined to learn more about the general quality of the sustainability education provided by classic schoolbooks. For the assessment, three reviewers analyzed the 16 books' quality standard using the Learning Object Review Instrument (LORI) by Nesbit et al. [16]. The LORI method assesses the items in seven categories on a 5-point scale with 5 being the maximum score. The schoolbooks showed a score range in between 3.3

and 4.3 with an average (arithmetic) score of 3.9. Quality of content was expectably high with more than 90 % fulfillment rate for the criteria, correlating a score of 4.4, The major weak spots were located within the categories "Feedback and Adaptability" (average score of 3,3) and "Conformity with Learning Goals" (average score of 3,5). Eight out of 16 schoolbooks did not name the learning goals of their units. Also eight books lacked an answer section to the units' tasks where students could check their answers and could thus judge their knowledge gain. Only one book set tasks designed to fit different learner's levels. The major drawbacks assessable with LORI were therefore obstacles for self-regulated learning. 50 % of the books left students unclear about what it is they are supposed to learn, why they are supposed to learn those things and if they actually succeeded in learning something.

Those books are strictly committed to an old-fashion teacher-centered learning model, thus keeping students in a role of passive learners instead of turning them into active solution seekers. By mere didactic design, those books fail to respect the basic element of ESD, which is assisting students to develop *Gestaltungskompetenz*. Even though they teach theoretic elements of what is considered to be necessary knowledge in the sense of ESD, they do not just fail to assist but actually hinder the students' skills development. Therefore, those books in themselves cannot be considered sustainable.

Thus, although schoolbook quality is comparatively high in general, their content selection does represent neither the complexity nor core topics of sustainable development such as sustainable manufacturing. Moreover, the didactic design hinders the students in developing *Gestaltungskompetenz*, the main goal of ESD.

2.3. Repositories

In order to describe the state of OER as a possible tool for ESD in Germany, it is necessary to look at the repositories that are established to provide teachers with materials additional to the classic textbooks with their restricted view on the teaching content and their media-inherent lack of representing current affairs. In Germany federal as well as national repositories for teaching materials exist. They get complemented by non-governmental repositories of which only the four widely used non-commercial respositories *Center for Teaching Media on the Internet (ZUM)*, *Lehrer-Online*, *4 teachers* and the repository of the *Siemens Foundation* were included, since the analysis aimed at understanding OER in Germany – which are by definition free of costs. The 17 major governmental repositories, including 15 federal and two national ones, and the four non-governmental repositories were analyzed according to a set of characteristics covering quantity, quality, actuality, and availability of the offered materials as well as the repository structure. Included content covered the cone-structured, e.g. the increasingly narrowed, fields 1. sustainability, 2. sustainable development and 3. sustainable manufacturing.

The national repositories scored distinctly higher than the federal governmental repositories. The latter are highly inconsistent regarding structure, e.g. explicitly marking items as OER. They also differ dramatically according to the number of items or item type. While the repository of the federal state Schleswig-Holstein lists more than 2.500 items on sustainability, including almost 500 that are connected to sustainable manufacturing, Bavaria's repository is linked to 16 sustainability items and none discussing sustainable manufacturing. However, it has to be mentioned that the great majority of those 500 manufacturing-related items from Schleswig-Holstein cannot be considered fit for educational (re)use. The item type ranges from detailed exercise sheets to offers for marginally described project days by external providers or news items on educational policies. All in all, the quality of the materials offered by the federal repositories is comparatively low. In many cases it is difficult to see how they could be considered teaching materials at all.

The national repositories list more selected materials. However, to gain access to the single items, the user is still directed through the heterogeneous federal repositories, and has to deal with its user-unfriendly environment nevertheless. Hence, it is not surprising that the teachers from the sample interviews stated that they and their colleagues hardly ever made use of any official repositories since the findability of useful materials on the so-called *Bildungsserver* (in English: Educational Servers) was extremely low. If the questioned teachers used repositories, they usually chose non-governmental ones. The analysis of those showed that they were indeed superior to their governmental counterparts regarding item quality, item findability and repository structure, allowing for better usability. Materials offered in those repositories were ready to use in class, e.g. logically structured content and exercises appealingly designed. They could usually be downloaded straight from the site and three out of the four repositories offered substantial filter functions e.g. by school type, class, subject, media, and license.

2.4. National and international OER analysis

In 2015, a search for German OER on sustainable development linked with topics of technology or industry targeting the 9th and 10th grade brought 29 results of which 18 also included at least one working sheet to use in class. Most of them had been developed for the subject geography, social sciences, biology, politics, religion/ethics, and economics, although none displayed its connections to the educational frameworks.

The LORI assessment showed an average (arithmetic) score of 3.6. Although some resources, especially those from official bodies, scored very high, only 55 % had good (4) or very good (5) results at the assessment of content quality (Figure 2). Another weak spot has been identified to be design: Only 10 out of 29 items scored good to very good in this respect. 62 % had high or very high congruency with the defined learning goals and 63 % included motivational elements such as varying exercise formats. Generally OER scored lower than the sustainability sections of geography books for the same target group; those having an average (arithmetic) score of 3.9.

However, only 18 out of those 29 items (62 %) defined learning goals in the first place. Although 26 items (90 %) formulated exercises, no more than 8 (26 %) offered exemplary answers for students to assess their learning success. Therefore, learning goals stayed mostly unclear and the materials were obviously not designed for self-centered learning, thus keeping students in a passive learning situation, depending on teachers' input and guidance when trying to learn using the free materials.

Furthermore, it must be said, that the analyzed items did not show a very high level of openness, since none were produced in an open format that would allow teachers or students to adapt the content. Also none were published under a creative commons (CC) license, thus ensuring free use and distribution. Three items were explicitly declared as "free to use" until a set date when the program under which they had been developed, stopped. Only one item gave a general allowance for unlimited free use although not using the legally unequivocal form of CCs. So, in a strict sense one could say that there are no real OER on sustainable development linked with technology or industry in Germany. However, the authors chose a less narrow interpretation of OER for being able to capture the current situation of manufacturing-related ESD in Germany and abroad.

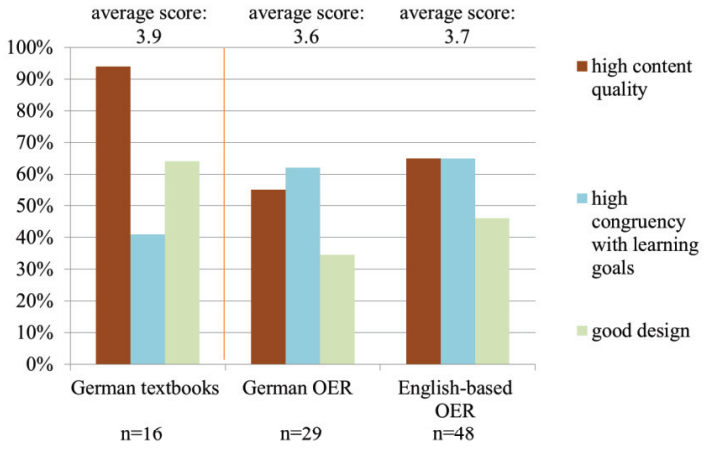

Figure 2. Comparison of German and English OER with German geography textbooks

The exemplary international search for English OER on sustainability and technology or sustainability and industry for the same target group (n=48, 23 including working sheets, 131 identified items total) revealed the USA and Canada to be the main producers of OER on the topic for this specific target group. However, there are also free English teaching materials accessible by providers from the UK, Australia, Norway, and France among others. The LORI assessment of 48 items that met the requirements of topic and target group best, showed a slightly higher score of the English OER than of those produced in German language, the average (arithmetic) score of the international OER being 3.7. 65 % of the English-based OER were assessed to have good or very good content quality and congruency with the learning goals. 46 % of the assessed items scored good to very good with regard to design. Still, the link to

core sustainable manufacturing topics was only marginal in most cases. This is a gap that needs to be filled if the topic shall stand a chance to get included in high school education.

Of the 23 items that included working sheets, 19 defined learning goals, this making it a 83 % fulfillment rate (see Figure 3). 18 items (78 %) formulated exercises but only 10 items (44 %) gave exemplary answers, thus the ratio of materials setting exercises providing chances for self-centered learning was noticeably better than with German OER. English-based OER also had a greater probability of making use of the full OER potential by using open formats at least for some of the offered materials (9 items; 39 %) and publishing under a creative commons license (9 items; 39 %). Nevertheless, there is obviously still potential for improvement.

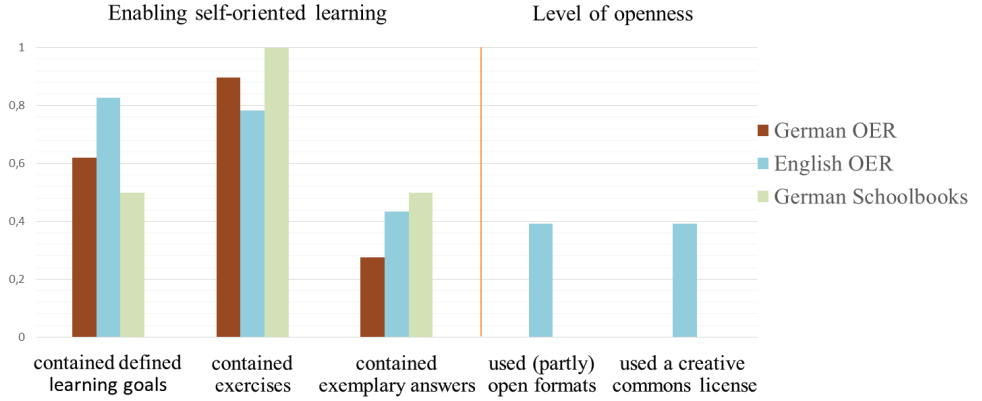

Figure 3. Teaching material analysis: self-oriented learning and openness (relative frequency)

Especially OER produced for the USA was often systematically characterized according to its links to educational frameworks and learning and competency goals. This can be considered an effect of well-structured repositories that require the producer to define those links before publishing the materials, since those data were mainly not integrated in the materials themselves but on the website on which they were offered.

3. University goes School: Development of OER for ESD within CRC 1026

Publicly funded science has an invaluable advantage when producing OER: it is considered neutral and exact in the highly competitive arena of sustainable manufacturing, thus its products are granted high creditability [17]. The Public Awareness project of CRC 1026 has taken on the responsibility of a publicly funded research project and committed its research and development work to the service of the public by producing OER for gaps identified during research, according to the expertise of CRC 1026, starting with a basic workbook containing three teaching units and additional teachers' materials on sustainable manufacturing for the 9th and 10th grade.

For a rough didactic framework, a reduced learning spiral oriented at Mattes [18] was chosen for structuring each teaching unit. The model arranges the different didactic phases of a lesson in a time flow, according to their student- or teacher-orientation. Summed up, the procedure starts with teacher-oriented learning, requiring increasing self- and group study as the lessons proceeds and finishing by teacher-led concluding elements, merging the individual learning results. Obviously the content must be general in the beginning, using every day's experiences of the target group as starting point. It gets more specific as the lesson proceeds. In the end of the lesson, exercises ask students to transfer the acquired principles to other fields.

When creating the content for the single didactic phases within each teaching unit, the desirable competencies defined by the educational frameworks served as constant reference point. Resource consumption in manufacturing is the central theme of the OER developed by CRC 1026, covering matters of human, natural and economic resources. In a first teaching unit, general knowledge on sustainable development was linked to manufacturing issues, e.g. the three pillars of sustainability were explained from a manufacturing perspective. This was then exemplified by a second unit using bicycle production as an example for discussing more specific sustainability issues within global value creation such as producing in low-wage countries, distributed production and CO_2 emissions. A third unit addressed

Maintenance, Repair and Overhaul as clearly technical topics of sustainable manufacturing, also addressing e.g. planned obsolescence. Since the material was supposed to be usable in different proficiency levels a focus was set on internal differentiation. Therefore, exercises were designed serving three levels of difficulty.

To help teachers actually teaching the new content additional teachers' materials have been produced, classifying each section according to the proposed teaching method, equipment needed and an approximate time frame. This classification is followed by a definition of the learning goal for the chapter, a description of the proposed didactic structure, sample solutions for the section's tasks, varied tasks for different learners' levels, proposals for further teaching content, sources as well as master copies needed for the proposed teaching method. For better orientation two tables have been included in the beginning of the teachers' materials, one showing the links of the materials' content to the educational frameworks, the other stating explicitly which exercise and which section serves what particular competency.

The CRC 1026 invested in a professional designer for layout and graphics. Since OER are free of charge and free to adapt and use it is of utmost importance to either only use graphics that are offered under a global commons license or produce them explicitly as such. A great challenge when creating OER is adaptability. A publishing licence allowing for adaptation is no benefit if the format of the offered materials does not allow for adaptation. Therefore, it is the designer's task to use a design software that most teachers or even students have access to. The researchers of CRC 1026 decided to design their OER in *Microsoft Powerpoint* in order to admit for (ex-)changing graphics or text blocks easily. Apart from integration into the repositories, aseperate blog is established to increase findability when using common search engines.

4. Conclusion

Sustainable development needs high quality ESD. In Germany, the educational frameworks have been rewritten to include ESD implicitly by directing all educational efforts towards fostering *Gestaltungskompetenz* within the students. Explicitly it is scheduled mainly for the 9th and 10th grade, especially for geography classes. An analysis of the corresponding schoolbooks showed that they might be good in graphic design and offer easily applicable didactic structures but they leave out major issues of a sustainable development, such as sustainable manufacturing and the complexity of the sustainability concept. What is more, not only by their content selection but also by their didactic structure do current schoolbooks actually hinder students' development of *Gestaltungskompetenz*.

Those might be some of the reasons why teachers complain about the lack of adequate teaching materials for teaching sustainable development and manufacturing-related issues. A promising approach in the context of effective ESD are Open Educational Resources. Those free teaching materials can cover a great variety of topics whereas printed schoolbooks are naturally restricted to a rather sketchy representation of complex topics, due to limited space and the need to keep the content generically enough for it to be still up-to-date after some years. Although some free German and English-based teaching materials do exist that could complement the schoolbooks' disadvantages, especially the German ones do not make use of the true OER potential by ignoring the use of creative commons licenses and open formats. Furthermore, they often ignore didactic demands of good ESD with regard to promoting the development of *Gestaltungskompetenz*. Nevertheless, there are visible efforts undertaken by OER producers, especially of English-based materials, towards competencies-orientation and increased openness – which cannot be said for the classic German schoolbooks.

Unfortunately, in Germany, good OER are hard to find. Especially official repositories lack filtering functions and quality control. German OER usually also lack clear connections with the educational frameworks that teachers are bound to fulfill and thereby fail to give teachers information on how these specific OER could be useful to them without them having to read through the entire material – which, by the amount of inappropriate OER, could be considered a waste of time. By developing teaching materials on sustainable manufacturing avoiding the common lacks of German OER, the Collaborative Research Center 1026 has made a significant contribution to filling the gaps in German Education for Sustainable Development.

Methodologically, the LORI method for assessing OER quality helps to separate the wheat from the shaft to identify the population for further analysis. However, when it comes to more specific demands of OER or competency-oriented didactic design, further assessment categories are needed. For this, it would be necessary to develop a systematic

approach for structuring the big variety of characteristics found in free teaching materials, defining them, among others, according to their learning design and especially to their level of openness.

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