

How to shape education for a sustainable circular bioeconomy?

Conclusions from the GBS2020 Workshop on Education, training & capacity building

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Executive Summary

'Bioeconomy is the production, utilization and conservation of biological resources, including related knowledge, science, technology, and innovation, to provide information, products, processes and services across all economic sectors aiming toward a sustainable economy' [1]. This description of the bioeconomy, as given by the GBS2018 Communique shows that the bioeconomy embraces many sectors, disciplines and their interlinkages, as well as the element of change towards sustainability. To realize the transformation towards a sustainable bioeconomy experts are required. For this purpose, educational programs have to be developed at different levels, making sure that the future workforce responds to the upcoming needs of all bioeconomy sectors (primary production, industry, etc.) and across bioeconomy disciplines (e.g. at the interface of agronomy, biorefining, ecology, and other disciplines) as well as to the requirements of sustainability and circularity. It is very much required that in each step of the value chain of the sustainable circular bioeconomy (SCB), these aspects are considered in a holistic approach. However, this holistic approach should always be based on scientific valuation processes and innovative research strategies.

It is advised not to draw a clear line between scientific discipline-focused programs and general bioeconomy programs for the sustainable bioeconomy of tomorrow. We instead call for science-based programs that also allow further education in relevant aspects of the bioeconomy, including ethics, economics, and law. Such programs will terminate disciplinary thinking and instead adopt an overall interdisciplinary learning and teaching approach. At the same time, innovative curricula must be driven by academic and industrial experts as well as civil society to bridge the gap between university and applied research and ensure the relevance and acceptance of teaching contents. This will necessarily involve "a change of educational culture" (Sterling, 2001). In general, educators must be trained and supported to facilitate interdisciplinary and transformative learning arrangements. Problem-based approaches instead of content-based teaching or small-group reflection instead of teacher-centered lecturing are potential ways forward. Transdisciplinarity is the next logical step in SCB education. It integrates non-academic knowledge in scientific research and includes the public and industry in the development and delivery of curricula (schools, universities, and vocational training).

While higher education surely plays an important role in the further deployment of bioeconomic principles in our economic systems, it is agreed that life-long learning is also crucial for realizing the transition. A thriving of bio-based industries heavily depends on their opportunities to train and further educate the available personnel. Furthermore, investments into individual life-long learning are a necessity for the social sustainability of the structural changes required by the SCB transition. It is therefore recommended to involve SCB into education's curricula at each level: Primary schools, high schools, universities, industry, LLL concepts, and into formats that foster the active public engagement in the transformation process.

The expertise required in the SCB workforce in the industry by 2030+ was identified as: Knowledge transfer from lab to industry; critical thinking and problem-solving abilities, knowledge in business models and project management; knowledge about the principles of sustainable development and the circular economy; knowledge in bio-based markets and techno-economic expertise.

It is acknowledged that different geographical regions have different needs and expectations in bioeconomy (education). Only when we recognize the regional differences, a flourishing global bioeconomy can be ensured and for a global success of SCB international cooperation is essential.

Background: The need to educate for a sustainable circular bioeconomy (SCB)

Globally, there are diverse regional and national strategies that envisage the shift towards a bioeconomy. To realize this transformation, bioeconomy experts are required who are able (I) to respond to the upcoming needs of the specific bioeconomy sectors, (II) to bridge the interfaces between bioeconomy disciplines, and (III) to attend to the principles of sustainability and circularity.

To meet this triple demand on SCB education, interdisciplinary cooperation in the workforce is required to address the scientific, technical, economic, and social challenges of our times. Appropriate education programs need to combine the provision of disciplinary, inter-, and transdisciplinary competences with the conveyance of systems thinking and the stimulation of creativity for new solutions. The range of education institutions within a country have valid differences in their missions for delivering the workforce expertise required at the different educational levels. Such differences can also be identified between regions and globally and need to be considered when planning educational programs. In the GBS2020 workshop “How to shape education for a sustainable circular bioeconomy?” the different skills requirements for the future SCB experts were discussed from six different perspectives (see sessions a to f below) on the background of the following assumptions:

1. A major challenge in SCB education is to develop tertiary education programs to educate bioeconomy graduates that meet the wide range in expertise required in the SCB workforce including technical and scientific knowledge as well as social and personal skills to support the transition to a SCB.
2. There are gaps in bioeconomy education presently offered by universities and non-academic training facilities that need to be identified and addressed.
3. For the development of SCB educational programs it is crucial to consider the pros and cons of establishing specific discipline-focused programs that provide an additional SCB overview versus genuine bioeconomy programs that impart systemic knowledge across the different disciplines of the SCB.
4. Life-long learning concepts are required to support a diversity of career pathways in the SCB.
5. There are different expectations and requirements nationally, regionally, and globally for the expertise in the SCB workforce that must be taken account of. At the same time, there is a lot of value to be derived from multinational collaborations to share and promote education, training, and capacity building approaches.
6. Strategies are required to better integrate SCB in pre-academic educational programs by, among others, linking teachers with practice partners in order to understand the demands on the future workforce. That way, school pupils will be made aware of the SCB, which may eventually influence their career choices.

Addressing the needs in a workshop: The workshop design

The GBS2020 workshop on education, training & capacity building was aiming at identifying and discussing gaps and developing concepts for a future SCB education against the backdrop of the assumptions (see above). To reach this goal the workshop was structured in six parallel working groups, with different participants and having a different focus.

1. Plenary session (45 min)

In a plenary session short input statements of the different sub-workshop coordinators or invited speakers were given to present the respective topic and to introduce to the questions to be addressed as a basis for understanding and discussion. At this stage the participants got a common knowledge of the different perspectives and could choose to which topic they wanted to contribute in the following sub-workshops.

2. Six parallel working group sessions (up to 70 minutes)

Working group sessions topics:

- a. Education in synthetic biology - A role model for the education of next generation bioeconomy experts?
- b. How should interdisciplinary education and training - in contrast to multidisciplinary education - be developed to ensure that all graduates are well prepared for their career pathways in the SCB?
- c. Skills and knowledge requirements for system changers that are able to move the transition to a truly sustainable bioeconomy.
- d. Interfacing industry requirements, megatrends and bioeconomy education: Top-down and bottom-up movers and drivers.
- e. Do current regional or national perspectives shape education for a sustainable circular bioeconomy?
- f. Strategies to implement the sustainable circular bioeconomy beyond tertiary education (including primary and secondary education) – educate and engage the educators.

Six parallel working group sessions (one on each topic a – f) were performed to involve the participants into the discussion and to include as many as possible perspectives for the elaboration of recommendations. To ensure a broad stakeholder and international participation, the working group leaders invited representatives of different stakeholder groups (international students, university teacher, industry representatives, politicians, NGOs, International organizations and networks) and of different regions globally for structured inputs in the sub-workshops. Within the sub-workshops interactive formats have been favored, which allowed intensive discussions and exchange.

3. Wrap up by the Workshop and Sub-Workshop coordinators.

After the workshop the sub-workshop coordinators prepared a summary of the main results of their sub-sessions along the above discussed central assumptions. These were summarized by the workshop coordinators in this document.

Outcomes

1. Development of tertiary education programs

The challenge to develop tertiary education programs to educate bioeconomy graduates that meet the wide range in expertise required in the SCB workforce including technical and scientific knowledge as well as social and personal skills to support the transition to a SCB.

The development of tertiary education to educate bioeconomy experts is challenged by the diversity of skills demands which span between disciplinary expertise and the capability to apply interdisciplinary skills to account for the systemic character of the SCB.

- The expertise required in the academic SCB workforce for the industry by 2030+ was identified as follows:
 - Research & Innovation
Knowledge transfer: from Lab to Industry, Innovation, and Change
 - Personal Initiative/Entrepreneurship
Critical thinking, Problem solving
 - Management
Development of business models, Project management
 - Sustainability & Industry
Circular economy / Zero waste industry/ Sustainable competitiveness /
Specialists in bio-based sector business
Bio-based market knowledge & techno-economic expertise Identify and create market application for new bio-based products
- The main challenge in tertiary bioeconomy education is to move **from multi- to inter- and transdisciplinary education:**
 - Today's university graduates are usually trained in multidisciplinary. Actual knowledge on interdisciplinary thinking is of high practical relevance but so far mostly acquired in 'learning by doing'.
 - It is important to **break disciplinary thinking** and instead have an overall interdisciplinary learning and teaching approach that employs academic and industrial experts to **bridge the gap between university and applied research**. This requires:
 - Technical skills and entrepreneurial mind-sets considering ethics and the societal impact of bioeconomic innovations.
 - Leadership competence: to be able to act and work in an interdisciplinary way, as decisions need to be made, which might be a compromise for all.
 - Communication skills to reach out to others.
- SCB tertiary education will also require institutional change in education systems
 - **Subjects of bioeconomy and sustainability to be anchored within current curricula.**
 - Faster advances towards a SCB are prevented by outdated academic standards. **A change in learning environments is necessary:** From education about sustainability within classrooms to a sustainable education beyond.
 - In general, **educators must be continuously trained to facilitate interdisciplinary and transformative learning environments**. University teachers have to be role models by working themselves in interdisciplinary settings and dedicate their research to the SCB. In many instances, this will also require a change in departmental structures and the deconstruction of hierarchies between teacher and student. This includes that a teacher in one discipline might be on the level of a student in another.

- **Democratization of SCB education**, novel teaching technologies like MOOCs and other tools need to be fostered and restriction free. This will lead to a globally more even distribution of incremental knowledge.
- To enable a global contribution to the future of bioeconomy, it is highly valuable and important to **make tertiary education also available to the countries of the global South**. For instance, synthetic biologists worldwide made great efforts to make theoretical as well as practical education accessible. [Aminolabs](#) and the cell-free education kit of [Biobits](#) are successful examples. Overall, synthetic biology's efforts to educate and be transparent with programs including iGEM, a student synthetic biology competition, open labs, and MOOCs can be applied as a role model for other disciplines within the bioeconomy.

2. Identification of gaps in bioeconomy education

Gaps in bioeconomy education presently offered by universities and non-academic training facilities need to be identified and addressed.

- It is acknowledged that we need to **bridge the gap between science, industry, economics, policy, and society**. Education needs to ensure an improved understanding between the different fields. The overall goal must be to raise awareness of the possible impact the future SCB holds.
- It is recognized that the **SCB is not sufficiently represented in higher education programs globally**, either as standalone programs or embedded in discipline specific degree programs. The ethos of the SCB (including the systemic approach, the requirements of sustainability, the need for cooperation etc.) should be embedded in the mind-set of all our graduates from disciplines related to it. The challenge is to embed that ethos in graduates from discipline specific degree programs focusing on component parts of the SCB, e.g., food science and technology, crop protection, etc.
- Industry stakeholders state that current education systems do not convey the **necessary skills required by the industry** and that the educational programs are very slow in adjusting to new industrial requirements, let alone in contributing to the progress of the sector.
- In terms of personal skills, the gaps include the following:
 - **Systems thinking** to overcome reductionist approaches and to convert from the perception of linear production systems to a vision of a SCB
 - **Values and future thinking** to enable the protagonists of a SCB transition to sketch future scenarios and consider societal values.
 - **Collaboration/cooperation skills** to enhance collaboration between industry and educational institutions.
- To better **align industry needs with skills taught**, vocational training has been identified as important gap. For educational institutions on the other hand it is important that industry provides internships for students. There is a need for a strong culture of encouraging employment of interns and mentoring students by employees in industry.
- The above together, complemented with transversal technical knowledge, will facilitate the valorization of bioeconomic innovation in a way that society benefits. In addition, competences are necessary that enable to bioeconomy experts to raise the technical and

conceptual awareness across society (as for example concluded in the Interreg Netherlands/Flanders Project “[Borderless Biobased Education](#)”, 2018).

- In order to achieve the overall goal of educating and informing the entire society, **communication skills** are essential. SCB communication must be target group specific to acknowledge the diverse levels of education, interests, and needs across the global society.

3. Discipline-focused versus general bioeconomy programs

For the development of bioeconomy educational programs it is crucial to consider the pros and cons of establishing specific discipline-focused programs that provide an additional SCB overview versus genuine bioeconomy programs that imparts systemic knowledge across the different disciplines of the SCB.

- It is advised ***not to draw a clear line between scientific discipline-focused programs and general bioeconomy programs*** for the SCB. Science-based programs are required that allow the integration of relevant aspects of the SCB, including ethics, economics, and law. Also, it must be ensured that scientific results and visions are communicated to legislators and other stakeholders in an understandable and transparent way. This will also allow experts with non-scientific backgrounds, like lawyers and politicians, to gain a deep understanding of the science behind the SCB. It is very much required that in each step of the SCB value chain the aspects are considered in a holistic approach. However, this holistic approach must always be based on the scientific valuation processes and innovative research strategies.
- Companies need specialists with generalist competences, but at the same time, they need “**enablers**”: employees who are responsible for creating an interdisciplinary and innovation friendly environment and who connect people.
- It is agreed that thinking in disciplines should be overcome to achieve a SCB transition. For the development of education programs, this requires a step-wise alignment: While in **multidisciplinary** education the contents from different disciplines are taught parallel to each other (additive), **interdisciplinary** education teaches these in an integrated way. The disciplinary knowledge is blended.
 - Most of the workshop participants have acquired interdisciplinary thinking skills by practicing interdisciplinarity. However, most of them stated that some kind of dedicated courses on interdisciplinary skills would be very beneficial.
- **Transdisciplinarity** is the next logical step in SCB education. It integrates non-academic knowledge and includes the public community and industry in the development of curricula (schools, universities and vocational training). This is perceived as a promising way to organize education as it enables students to learn in and think about real-world problems.
- In **discipline-specific programs** the concept of the SCB has to be embedded across the curriculum and enable students to understand systems from different perspectives (→ Overcoming reductionist approaches and seeing the world in a “web-like way”). This necessarily involves lecturers who have the knowledge and understanding of the SCB and a respective design of the learning outcomes within the degree programs. In addition, it requires **contextualized and interactive learning activities** that ideally result in emotional engagement.

4. Delivering life-long learning concepts

Delivering life-long learning concepts to support a diversity of career pathways in the SCB.

- It is agreed that life-long learning is very ***important from the industrial and personal perspective***. A thriving of bio-based industries heavily depends on their opportunities to train and further educate the available personnel. Furthermore, investments into individual life-long learning are a necessity for the social sustainability of the structural changes required by the SCB transition.
- Life-long learning is only possible where educational material and scientific findings are ***available to the public*** (e.g., published open source). Life-long learning and self-learning need to be recognized as additional training and degrees. These should be freely available. This can be facilitated by the following:
 - Digitalization of educational offers as well as the provision of instructions for small scientific experiments at home (e.g., with the help of purchased kits) allow for a ***democratization and reduction of entry thresholds for education***. This includes many technical skills that become available to the global community, inducing the global south.
 - ***Training on the job***: Additional courses which can be attended in parallel to a full-time job like, e.g., blended learning formats, MOOCs, and other courses, etc.
 - ***Outreach of university education and research***
 - In-house training programs in firms for site specific training, new technology training programs, or career development programs are concepts which create a number of opportunities for universities to engage in life-long learning.
 - Collaboration with non-academics, practitioners, and local administration is crucial for educating professionals who are supposed to actively support the SCB transition. While students can learn a lot from these stakeholders, we also expect an exchange in the sense that students can influence the way how organizations and individuals of private and public business think and act.

5. Different expectations nationally, regionally, and globally for the SCB expertise

Different expectations and requirements nationally, regionally, and globally for the expertise in the SCB workforce must be taken account of. At the same time, there is a lot of value to be derived from multinational collaborations to share and promote education, training, and capacity building approaches.

- It is acknowledged that ***different geographical regions have different needs and expectations*** towards the SCB (education). During the workshop, speakers and participants from all continents contributed to the discussion and concluded: only when we recognize the regional differences, a flourishing global bioeconomy can be ensured.
- It is agreed that ***international cooperation is essential for success***. We should engage globally to share experience and understanding. This exchange is currently expanding and accelerating through digital teaching and collaboration, as can be observed in relation with the current COVID-19 pandemic. Efforts such as the workshops at the GBS2020 and the Global Bioeconomy Alliance facilitate the exchange of experience and the sharing of best practices. The UNESCO supports this endeavor to work with centers of excellence and universities to achieve international collaboration in bioeconomy education.
- It was concluded that in countries across the globe the concept of the SCB yet need to be better embedded in discipline specific degree programs. So far, graduates usually do not leave their university with ***the ethos of the SCB*** to influence their actions during their careers.
- Through education, we need to ensure that the biotechnological revolution we are currently witnessing will lead to a future SCB that will be beneficial not only for people from the global North but also ***holds great benefits and promises for the population of the global South***. The synthetic biology approach of defining and standardizing biological elements to solve problems on a regional level allows capacity building and training across borders. It leads to an increased acceptance of SCB.
- It is agreed that ***intercultural training*** in the classroom and outside is very conducive to acquire and reflect on different viewpoints/worldviews, which is seen as an important experience to train transformative skills required for a SCB transition.

6. Identification of strategies to better integrate SCB in pre-academic educational programs

Strategies are required to better integrate SCB in pre-academic educational programs by, among others, linking teachers with practice partners in order to understand the demands on the future workforce. That way, school pupils will be made aware of the SCB, which may eventually influence their career choices.

Pre-academic educational programs are generally considered an important prerequisite for preparing societies for the SCB and also to anchor SCB throughout the societies. The following entry points for involving SCB into primary and secondary education were identified:

- It is necessary to **integrate bioeconomy into education's curricula**. So far, topics around the SCB usually are "extra" to the curriculum.
- Teachers encounter language barriers, they need materials in their native language to use it in their classes (video animations, visuals, games, quizzes...) → Provide good teaching material in the respective language. The School box is an example to the point, which was developed in the EU funded project BLOOM [2]
- Teachers who were unfamiliar with interdisciplinary approaches felt that **cooperation with peers** helped to enable them to spread SCB in their schools. The setup of a community for teachers' support is necessary.
- A state of the art for SCB education and **life-long learning, especially for teaching personnel**, will be required in the future. Synthetic biology and leading research institutes within this discipline are making great efforts to achieve this. Concepts like **learning through research** approached by many different research facilities train scientific thinking, which will be the basis for any future career choices. Through awareness raising and education of the following generations, we increase the general understanding of controversial topics connected to bio-based products (e.g., synthetic biology or genetic engineering). That way, well-founded public opinion is possible regarding future technologies that are able to ensure sustainable lifestyles for the global population.

Conclusion

The involvement of experts from different disciplines and from primary and higher education as well as industry into a discussion about SCB educational requirements was very fruitful. Some of the findings will support the development or improvement of educational formats offered by the participant organizations. On the basis of the diversity of participants and questions addressed, the following points can be concluded to form the overall outcomes of the workshop.

SCB education must be all-encompassing

Globally, the development of strong expertise in specific disciplines is needed along with a broader bioeconomy education common to curricula at all levels of education and involving socioeconomic subjects and disciplines in addition to technical ones.

SCB education must be relevant

Frequently, industry stakeholders state that current education systems do not train the necessary skills required by the industry and that the changing pace of educational programs is very slow in adjusting to new industrial requirements or the progress of some sectors. The need to increase collaboration between industry and education institutions has been confirmed. There is a need for a strong culture of encouraging employment of interns and mentoring by employees in industry.

SCB education must cross disciplinary boundaries

Comparable approaches involve specific interdisciplinary programs. Anchoring subjects of bioeconomy and sustainability at educational institutions within current curricula is important but not sufficient for advancing the bioeconomy. The global exchange of best practices in creating new study courses, determined to the subject of bioeconomy, is very valuable. We can learn from teaching staff who work themselves interdisciplinary and are dedicated to bioeconomy. Examples are given at dedicated institutions with interdisciplinary teams and a departmental structure that facilitates the collaboration of different disciplines in a move forward step by step towards a global bioeconomy [3, 4].

SCB education must continue throughout a lifetime

The life-long learning aspect is very important from the industrial and personal perspective as the prosperity of industries depends very much on the opportunities to develop and train the available personnel and on investments into individual life-long learning. In-house training programs at industries for site-specific training, new technology training programs, and career development programs are concepts which create a number of opportunities for universities who offer these training programs. The current COVID-19 pandemic has accelerated collaborations through the digital teaching and enables to reach out and collaborate at all levels. Efforts such as the workshops at the GBS2020 and the Global Bioeconomy Alliance facilitate the exchange of experience and the sharing of best practices. Inclusion of bioeconomy in pre-academic programs is an important prerequisite for preparing societies to the bioeconomy and also anchor bioeconomy throughout the societies as well as to enable science-based decision making.

SCB education must be inclusive

Additionally, it was highlighted that education, knowledge bases, and ideally also materials need to be openly available. Modern education technologies can be applied as a tool to future democratizes education in the SCB sectors to ensure that the bioeconomic transformation is globally beneficial.

SCB education must be innovative

It was concluded that the educational programs delivering the knowledge base and workforce required for the transition to a SCB need to be innovative also in their methods. Thus, development of educational methods is not just a matter of choosing the right contents, but also innovative methods that provide systems and sustainability knowledge and the skills enabling to guide the sustainability transformation. It needs to be discussed in how far existing educational approaches can deliver this or whether and how existing educational structures need to evolve.

Clearly, the transition to a SCB requires an international approach. The forum of the GBS provides an excellent platform for the exchange on educational demands and cooperative approaches on the international level. Therefore, the topic of education will remain of key importance and should also be addressed at future events.

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