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Using Group Model Building to Foster Learning for Strategic Sustainable Development

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Abstract: Capability for strategic planning and decision-making toward sustainability requires both individuals and organizations from different sectors and disciplines to develop necessary skills and competencies. Therefore, a growing discussion has emerged within academia and practice around how pedagogical methods and tools can be utilized for this purpose. This paper seeks to contribute to this discussion by asking 'in which way may group model building be used to foster learning that leads to competency for strategic sustainable development?'. The potential of the group model building (GMB) process' steps and associated modeling to foster learning for strategic sustainable development (SSD) was analyzed using four case examples. Theory on learning for sustainability and key sustainability competencies were linked to elements of a process for strategic planning toward sustainability within the framework for strategic sustainable development (FSSD) as a reference model. The results provide a discussion on how GMB can be utilized to foster sustainability competencies and learning for sustainability that can contribute to SSD, hence a basis for continued research and ideas for course and curriculum development.

Keywords: learning for sustainability; sustainability competencies; strategic sustainable development; group model building

1. Introduction

Sustainable development is a global, transdisciplinary, and complex challenge that requires decision-makers and stakeholders from various areas to collectively and dramatically shift the way society including businesses operates today toward compliance with socio-ecological constraints. The urgency of sustainable development is reflected in the development of higher education pedagogy, programs, and curricula [1]. While sustainability may be understood as a state of balance between the Earth's socio-ecological systems in which society can satisfy human needs, see, e.g., [2], sustainable development is rather about the transition toward this state. If 'sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' [3], then a transition toward sustainability needs to be planned within constraints that can deliver the conditions required for current and future sustainability. Such constraints must be applied globally, at all levels of decision-making in society. Several authors have therefore highlighted the need for a strategic approach to achieving a sustainability transition, see, e.g., [4,5], and that can be referred to as strategic sustainable development (SSD). This is a core purpose of the Framework for Strategic Sustainable Development (FSSD), which is in contrast to other approaches to sustainable development, using principles instead of specific scenarios to define sustainability [6]. Coupled with a planning process that applies backcasting from these principles, decision-makers can be guided in describing the ecological and social constraints in a sustainable future, and to create a strategic plan toward this state. The eight sustainability principles are described in Figure 1.

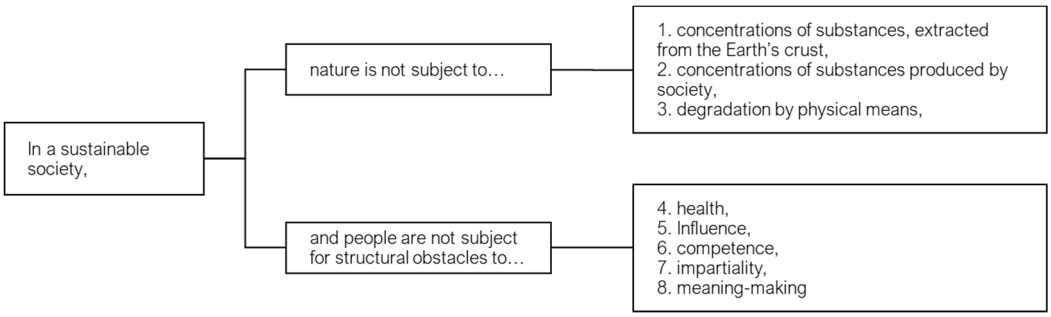

Figure 1. The eight sustainability principles of the Framework for Strategic Sustainable Development (FSSD) provide constraints for human activity in a sustainable socio-ecological system [6].

Capability for strategic planning and decision-making toward sustainability requires certain skills and competencies to be developed by both individuals and organizations in different sectors and disciplines, which allow them to work together toward an ambiguous and complex objective [5,7]. Developing such competencies is about learning for sustainability, i.e., acquiring knowledge and skills that can shift individual, organizational, and societal behavior that enables sustainable development [8]. Higher education, and within organizations, professional training, can contribute to this challenge by fostering such learning. However, instructors that aim to foster learning about sustainability are challenged by its complexity. In sustainability education, both social- and natural science must be addressed in a way that is graspable and relevant in the learners' context [9]. Therefore, a growing discussion has emerged in both academia and practice around how pedagogical methods and tools can be utilized for this purpose [10,11].

Group model building (GMB) is an established participatory system modeling method in which participants co-create a shared understanding of how a system behaves, and how the behavior can be changed by using causal modeling and dynamic system simulations. Such modeling can be useful for learning and planning in complex systems, and to guide efficient, or strategic, decision-making [12]. Therefore, participatory systems modeling, and simulation methods have become well-used in sustainability research and education, e.g., [13,14]. This paper seeks to contribute to this discussion by asking *'in which way may group model building be used to foster learning that leads to competency for strategic sustainable development?'*.

To address the research question, four cases of research and education in which GMB was combined with elements of FSSD's strategic planning process toward sustainability, were analyzed against key components of learning for sustainability and the characteristics of key sustainability competencies.

2. Research Approach

The research approach can be divided into three main phases. First, a theoretical reference model of key competencies for sustainability and characteristics for collaborative transformative learning was developed. Second, four previously conducted cases of GMB applications in strategic sustainability research and education were selected to provide secondary data to analyze in the next phase. Purposeful sampling, e.g., [15], was used to select cases using the following inclusion criteria: (i) conducted in different research or education projects, in different contexts in terms of sector, number of participants, type of participants, geographical setting, time, etc.; (ii) shared methodological approach and overall aim, i.e., participatory GMB to leverage competency development and learning for SSD, and finally (iv) access to data and opportunity to discuss it with the original author. In this way, this research aimed to meet some basic quality criteria for qualitative research including credibility and relevance [16]. In the final third phase, the proposed theoretical reference model was used as a lens in a qualitative content analysis [17]. The outcome of this phase was an analysis of the cases' contribution to key sustainability competencies and collaborative transformative learning for sustainability.

2.1. Developing a Theoretical Reference Model for Learning and Achieving Competencies for Strategic Sustainable Development

Sustainability transitions require (radical-) behavior change from individuals, organizations, and society at large, which is why stakeholders need to establish a shared definition of what sustainability is [6]. Therefore, learning for sustainability needs to be collaborative, allowing for different stakeholders to both contribute to, and take part of, a shared learning process [8]. Hence, learning for sustainability shares elements of project-based learning, where team members need to collectively decide on an objective, which the results of the project can be evaluated against. Then, participants together may collect information to which they apply analyses or experiments to gradually, i.e., in a progression, advance their learning in terms of knowledge, skills, collaboration, and facilitation [18].

However, collective and collaborative learning does not automatically foster radical behavior change. Incremental change, that is, accommodative learning, may lead to, e.g., relative improvements whilst transformative learning, the adoption of new values or thought paradigms, see, e.g., [19]. At the individual level, this can be compared with when students understand critical threshold concepts in a new course subject with complex, or 'troublesome', areas of knowledge [20]. At the organizational scale, this could be illustrated by a company that decides to introduce a new policy that favors sustainability, e.g., carbon emission reductions, although it will not, in the short-term, generate the best profit.

Transformative learning can be understood in terms of what Argyris and Schön (1978) describe as double-loop learning. *Single-loop* learning concerns incremental improvement of knowledge within traditional value structures, i.e., similar to accommodative learning. *Double-loop* learning, on the other hand, occurs when an individual or organization restructures values, norms, or priorities leading to radical behavior change based on the effect of an intervention in the current system [21]. As illustrated in the Kolb learning cycle, transformative learning may be understood as knowledge and skills that change ways of thinking and acting as a result of impressions from, interaction with, and reflection around reality [22]. A transformative learning experience is, henceforth, understood as an outcome of a double-loop learning event.

Continuing to assess the effect of learning activities and environments that aim to foster learning for sustainability leads to the concept of key sustainability competencies [23]. Several frameworks for sustainability competencies have been presented such as Albareda-Tiana et al.'s (2020) recent Sustainability Competency Map of Education Degrees [24]. Another well-known framework is that of Wiek et al. (2011), which presents five key sustainability competencies that can be used to guide education in sustainable development [25]. Despite the presence of new frameworks, and that authors have suggested changes or additions to Wiek et al., it has become widely accepted across various disciplines, see, e.g., [26]. Therefore, it was also adopted in this study. The five competencies are systems thinking competence, anticipatory competence, normative competence, strategic competence, and interpersonal competence. Acquiring these competencies involves learning about a range of concepts related to each competence and how to apply them using different methods and methodologies, collectively [25]. Table 1 summarizes the associated concepts for each of the five key competencies as well as suggested methods to develop the competency.

Systems thinking competency is about being able to analyze complex (multidisciplinary-) systems over different geographical scales and time intervals. Key components of systems thinking are comprehension, empirical verification, structure articulation, leverage points, and dynamics. Acquiring systems thinking skills requires systemic knowledge about concepts such as structure and function, causality and correlation, and decision-making. *Anticipatory competency* concerns the ability to create and assess descriptions of the future, in terms of challenges and opportunities, based on theoretical frameworks for sustainability and, or, sustainable development. Having anticipatory competency thus entails that individuals or organizations can articulate what constitutes a sustainable, or non-sustainable scenario using both qualitative and quantitative information. Simulation methods are useful for this as analyzing and evaluating future scenarios requires the comprehension of behaviors such as unintended consequences. *Normative* competency refers to the ability to navigate values, principles,

and objectives related to sustainability. It is required to enable comparative assessments of different strategies, plans, or solutions for sustainability. Hence, normative competence involves skills in mapping, specifying, applying, and evaluating such alternatives based on their compliance to what constitutes sustainability, i.e., knowledge about what is sustainable, and what is not. *Strategic competence* is about designing and implementing plans and actions that support a transition to sustainability. Such abilities require knowledge and application of concepts such as viability, feasibility, effectivity, efficiency, and systemic skills to avoid unintended consequences. In that, this competency also involves the capacity to understand and meet different stakeholder perspectives so that the right thing can be done at the right time. Finally, *interpersonal competency* involves the ability to facilitate collaborative and participatory research or problem-solving activities in an engaging and motivating way. Then, successful communication between different stakeholders can be enabled, but requires advanced communication skills [25].

Table 1. Five key sustainability competencies: some examples of related concepts and applicable teaching methods, adapted from Wiek et al. (2011).

Sustainability Competency	Examples of Related Concepts	Teaching Methods or Methodologies
Systems thinking	Variables, indicators, sub-systems, adaption feedback loops, causality, decisions, structures, multiple domains-social, ecological, technological, economic, values, needs	Qualitative and quantitative modelling, systems analysis, participatory modeling
Anticipatory	Time, dynamics, non-linearity, uncertainty, probability, possibility, risk, dependency, desirability	Scenario methods, forecasting, backcasting, participatory modelling
Normative	Sustainability principles, goals, targets, thresholds, responsibility, justice, safety, damage, harm, reinforcement, trade-offs.	Comparative multicriteria assessments, risk analysis, sustainability assessments, participatory methods
Strategic	Intentionality, transformation, transitions, governance, strategies, success, viability, feasibility, efficiency, effectiveness, obstacles, dependency, synergies	Decision-support methods, organizational change management, learning methods
Interpersonal	Collaboration, group dynamics, leadership, empathy, motivation	Teamwork methods, participatory methods

2.2. Participatory Group Model Building for Strategic Sustainable Development

Group model building (GMB) is a method for participatory systems modeling that aims to facilitate team learning and the creation of efficient decision support in complex systems [27]. In a series of five general steps, GMB targets different levels of learning about a system through application of different systems modeling techniques. The first steps consist of qualitative systems modeling, which is followed by dynamic modeling and simulation [28].

GMB, hence, aims to facilitate two learning cycles. The *first cycle,* represented by Steps 1–3, consists of collective co-creation of the models representing both current and future scenarios, and the effects of strategies that theoretically or logically could bridge between those two states. In the *second cycle,* participants collaborate in the creation of a plan or strategy to reach the future scenario and simulates the effect of the plan on the objective, thus facilitating a second learning loop [12].

In Step 1, problem articulation, participants together define the problem, if it is not already clearly specified. An example can be 'what are some efficient measures to improve the environmental performance of cars?'. The participants may annotate which variables belong to the system. In Step 2, the task is to formulate a dynamic hypothesis. In this step, participants may start to illustrate how the variables influence each other. CLDs can be used for this purpose, which qualitatively illustrate the

feedback behaviors within the system. Reinforcing and balancing relationships as well as delayed feedbacks can be visualized, and reference behavior diagrams (RBDs) can be used to further scrutinize the behavior of the variables over a time scale. In Step 3, a dynamic simulation model of the system is constructed, as the qualitatively modeled CLD are translated into quantitative stocks and flows over time. The result may be a system dynamic (SD) model. Step 4 involves model testing, allowing for smaller modifications. Finally, Step 5 involves policy design and evaluation [28].

Traditionally, GMB tools, CLDs and SD models are used for forecasting planning and not for scenarios such as sustainability, whose characteristics cannot be described in detail. Using a principle-based definition of sustainability as planning constraints in a GMB process can therefore be a way to describe the characteristics of sustainability, and to create and explore alternative pathways toward it [29]. In this way, GMB can support FSSD's strategic planning process toward sustainability, called the ABCD-process. Any organization that aims to organize their contribution to sustainable development can start by (Step A) envisioning a successful future where they operate within socio-ecological constraints as defined by the sustainability principles. In Step B, the organization evaluates the current misalignments of their operation in relation to these principles. In Step C, ideas for activities that could bridge the gap between the current (B) and the future (A) states are generated. Then, in Step D, the ideas are prioritized and organized into a strategic plan of goals and actions [6].

2.3. Proposed Reference Model

Based on the theory presented in the two previous sections, it was assumed that the degree to which participants of a participatory GMB process, framed by the FSSD, reached learning for sustainability. This learning may be associated with which steps of a general GMB process, along with which steps of the ABCD process for strategic planning sustainability were applied, which sustainability competencies were triggered, and, whether accommodated single- or double-loop learning was triggered. Theoretically, Step A should foster a normative competency, i.e., establish a common view of the sustainability challenge and goal scenario, using sustainability principles. Step B should encourage systems thinking skills, as the current scenario is described aiming to identify dependencies and leverage points. Steps C and D should furthermore help foster anticipatory and strategic competencies as ideas for new policies, plans, and strategies are ideated, discussed, and further selected with support from visualization and simulations. The development of interpersonal competency should be supported through the format and facilitation of the GMB process, e.g., through being participatory and motivational. As the purpose of the ABCD process is to facilitate planning for strategic sustainable development, it is assumed that the last step, D, should foster transformative, double-loop learning in the form of new plans or policies informed by a strategic sustainability perspective. The four cases will therefore be assessed in terms of:

(i) which steps in the ABCD process were conducted,
(ii) which competencies could be indicated through observations and participant feedback, and
(iii) the result of the GMB application and hence type of learning.

3. Cases of Group Model Building in Strategic Sustainable Development Research and Education

In research and education within the scope of the FSSD, GMB has been applied in different research areas such as sustainable product development [30,31], sustainable mobility [32], and in higher education [33–35]. Based on the secondary data retrieved from these cases, the following subsections provide case summaries and analyses against the proposed reference model.

3.1. Case 1. Group Model Building Workshop Method for Sustainable Product Design and Development

The GMB workshop for sustainable product design and development was designed with the aim of supporting cross-disciplinary teams of decision-makers in product developing companies to create a shared understanding of (i) what sustainability is for a specific company, and (ii) the implications of

sustainability criteria on their traditional decision criteria in a product design context. The workshop was facilitated by an expert who introduced the participants to a design case, to which some traditional product requirements, such as total cost of ownership, quality, and manufacturability, are presented as well as the prevailing sustainability criteria. Thereafter, participants were introduced to the modeling method (CLDs) and stepwise procedure, divided into groups, and provided with templates in which the results of the discussions were captured alongside co-created CLD. At the end of the workshop, participants shared their new learnings, together with discovered opportunities and challenges to meet both sustainability criteria and the traditional requirements. In this way, the participants were triggered to unravel conflicting perceptions and co-create a model in which their new system models of relationships and dependencies between sustainability criteria and product requirements were illustrated [30].

The method has evolved based on feedback from industrial partners [36] and observations from a set of four pilot-sessions. Reference behavior diagrams and causal loop diagrams were used together with templates and facilitation. Participants, in total more than 100 distributed over the sequence of five pilot workshops, represented both academia and industry as well as a range of disciplines covering, for example, sustainability science, product design and development, economics, business modeling, education for sustainability, engineering design and manufacturing, and software development. To ensure that all sustainability dimensions and lifecycle phases as well as a strategic sustainability perspective was included in the sustainability criteria, these were derived using an sustainable product development method [37,38].

To analyze the contribution sustainability competency development, and type of learning, the feedback, observations, and collected modeling materials, i.e., templates and notes, from all four workshops were used.

Analysis of Case 1

In Case 1, the workshop method applied the first two steps of the general GMB process and settled at using CLDs to discuss dependencies and leverage points to improve a design concept from a sustainability perspective. To apply a strategic sustainability perspective, leading sustainability criteria were used to represent the normative scenario of sustainability, hence corresponding to step A in the ABCD process. Step B is represented by the actual CLD modeling activity, and the workshop ended in a discussion about trade-offs, value drivers, and new findings, approaching Step C.

In Case 1, the GMB workshop method for sustainable product design, participant feedback mentioned concepts such as 'discussions', 'widened perspective', 'what sustainability means', 'visualize complexity', and 'dependencies'. 'Widened perspective' and 'visualize complexity' indicate that the method triggered training of concepts related to the systems thinking competency. 'What sustainability means' can be linked to the anticipatory competence, and 'dependencies' relates to the anticipatory competence. 'Discussions' might be related to concepts of interpersonal competency. Guiding templates provided each team with instructions on how to utilize RBDs and CLDs to scrutinize relationships between system variables, and that provided a place to document what the team collectively identified as important aspects, i.e., trade-offs and synergies between traditional design variables and socio-ecological sustainability criteria. In this regard, the method might contribute to the strategic competency, but no actual plan was decided and therefore this element of the method might in fact be more related to the anticipatory competence. The workshop utilized RBDs, CLDs, templates, group discussions, and peer feedback. The output was, in summary, guidance for decision-makers with regard to, for example, weighting of requirements, but participants also mentioned that the workshop in itself could be useful in education or as competence development for practitioners. No radical change in behavior was expected by the participants as a result of this exercise such as establishing a new policy, strategic plan, or selection of new product requirements, which could indicate a potential for double-loop transformative learning. Hence, this case shares more similarities with accommodative learning rather than transformative.

3.2. Case 2. Introductory Procedure for Sustainability-Driven Design Optimization

Byggeth et al. (2007), included SD models in an iterative optimization procedure that combined technical assessments with sustainability assessments to gradually refine design criteria [31]. With input from a design team at a water jet cutting machine manufacturer, three researchers used CLDs and RBDs to 'what are some relations between the water jet cutting life-cycle (and machine performance), its sustainability impacts and customer demand for water jet cutting?', to find leverage points for design optimization that were beneficial for the company, society, nature, and the customer. The company provided design criteria that were investigated using criteria for socio-ecological sustainability retrieved from a sustainability assessment, and performed by the researchers, which was guided by the sustainability principles [39]. The CLD, see Figure 2, was verified by the design team and provided the basis for the SD model, which further gave support in more sophisticated technical reasoning. For instance, the design team reported that they had realized that the moving weight influenced other aspects of machine performance such as cutting accuracy and speed. Due to these possible relationships between lightness, accuracy, and speed, a minimum requirement for accuracy and speed was set before the technical optimization study. The SD models gave a systems description of the technical performance parameters in water jet cutting in a sustainability context, and as a result, the design team obtained a widened perspective on the driving forces behind the sustainability impacts of water jet cutting. Thus, different stakeholders' perspectives could be clarified and the iterative optimization procedure that combined different assessments gave support in decision-making for the optimization of the machine. The main outcome of the study, which engaged three researchers and three designers, was a generic procedure to follow in order to identify win–win–win situations for the company, the customer, and society.

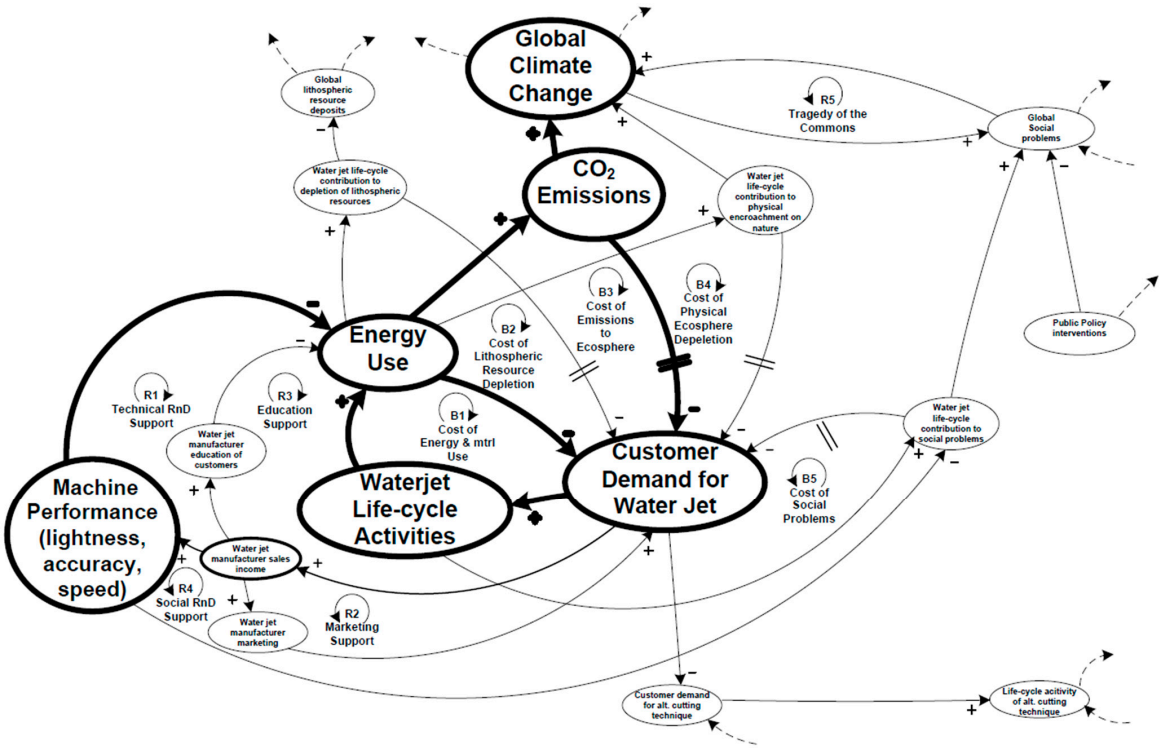

Figure 2. Causal loop diagram from the case study of a water jet cutting machine in Byggeth et al. (2007) showing some of the complexity among factors for machine performance, energy use, CO_2 emissions and global climate change [31].

To analyze the contribution to sustainability competency development and type of learning, the results as well as comments from the participants were used.

Analysis of Case 2

In Case 2, the A step was represented by the sustainability criteria derived from a sustainability assessment on the actual case product, which was guided by the sustainability principles. Step B was represented in the CLD model that mapped the systemic relationships between the design- and sustainability criteria. Step C was supported by the quantification of the CLD into a SD model, which informed the decision (i.e., step D) to introduce a minimum requirement for accuracy and speed into the design process.

In Case 2, the introductory procedure for sustainability-driven design optimization, it was possible to distinguish concepts such as 'systems description', 'sustainability context', 'widened perspective', 'driving forces', 'sustainability impacts', 'improved technical performance', 'important role in reducing', and 'energy and material use'. 'Systems description', 'widened perspective', and 'sustainability context' can be associated with systems thinking competency concepts. 'Sustainability impacts', 'important role in reducing', and 'energy and material use' all link to the normative competency. Finally, 'Driving forces', and previously mentioned 'important role . . . ' are comparable to anticipatory competency concepts. In this case, the CLD was also quantified into a SD model that was used to identify so-called 'win–win' scenarios. Hence, some strategic competency concepts might have been triggered. It is unclear whether the study contributed to changing any company strategy related to sustainability, and why it seems as if the study contributed to single-loop collaborative learning.

3.3. Case 3. Transport Strategy and Planning Using System Dynamics and Backcasting from Sustainability Principles

A longitudinal action research study that took place between 2011–2015 used GMB with CLD and SD modeling to strengthen the ABCD process for strategic planning toward sustainability in the context of sustainable transport. The around 100 study participants, of which 25 constituted the 'core reference group', represented stakeholders within the transport system in the region of Blekinge, Sweden. In Step A, the goal was to collectively describe what types of transport systems could exist inside the constraints of the sustainability principles, i.e., to create a shared mental model of the goal scenario being a sustainable transport system. This was achieved through activities such as stakeholder dialogue seminars. In Step B, the behavior of the current transport system was modeled by the research team using CLDs. The variables were retrieved from the previous stakeholder dialogues and the results from a qualitative Strategic Lifecycle Assessment [40]. This CLD visualized the current misalignments of the transport system compared to the goal scenario as well as which factors that might cause them, and hence potential leverage points for improvement measures. These variables were later translated into sustainability effect-indicators that were double-checked through traditional quantitative lifecycle assessment and lifecycle costing. In Step C, potential future solutions were discussed and generated with support from business modeling tools such as Blue Ocean Strategy and Business Model Canvas. Through simulating the effect of these solutions on the sustainability effect-indicators, potential pathways to the goal scenario could be discussed. Finally, in Step D, some solutions could be scrutinized, and a strategic plan could be defined through another iteration of stakeholder dialogues in a forum of key stakeholders, that is, representatives from each organization in the first stakeholder dialogue. Here, the validity and reliability of the CLDs and SD models were discussed through scenario simulations and model testing. The research study showed that it was possible, and useful, to combine a method for strategic planning toward sustainability together with the basic procedure for GMB. The researchers and experts managed to agree with the public and private stakeholder representatives on an overview of the challenges and opportunities for the regional transport sector. This common view was consolidated in an overarching roadmap that was published as both a book and a booklet, which were distributed broadly to both academic partners and society [32].

The results of each modeling step as well as the design of the GMB process including the use of tools as well as statements from participants collected in the report were used to analyze how this case contributed to sustainability competency development and type of learning.

Analysis of Case 3

Case 3 was designed based on the ABCD-process and utilized GMB to collect and model the relationships between various stakeholder perspectives in correlation to the sustainability principles and used SD models to simulate potential pathways to a state of compliance to those principles whilst satisfying stakeholder needs. As a roadmap of action was the result, all four steps were deployed.

The summary of Case 3 offers examples of concepts related to all five competencies that include 'several scenario pathways', 'a prioritized strategic plan built on the selected scenario', 'validity and reliability of CLDs and SD models were discussed', and 'scenario modeling and scenario testing', which can be associated with concepts for the strategic competency. Descriptions of multiple 'iteration of stakeholder dialogues' can be associated with the concepts related to the interpersonal competency. That multidisciplinary stakeholders, i.e., from both academia industry and society, agreed on an 'overview of the challenges and opportunities for the regional transport sector', and that those were consolidated and distributed both to academia and society as a plan strengthens the contribution to such competency whilst encouraging double-loop learning. Using the ABCD process for strategic planning in combination with sustainability principles and using scenario-methods such as CLD combined with quantitative tools such as LCA to derive measurable indicators relates to concepts within the systems thinking-, anticipatory-, and normative competencies.

3.4. Case 4. Group Model Building Applications within Higher Education Courses in Strategic Sustainable Development at Blekinge Institute of Technology

GMB activities are frequently used in higher education courses given at the department of Strategic Sustainable Development at Blekinge Institute of Technology. Students at the transdisciplinary, 1-year, master's program in strategic leadership toward sustainability are taught, and encouraged to use, simplified CLDs as a core methodology to model and identify sustainability leverage points within complex socio-ecological systems [33]. The program teaches and applies the ABCD process as a method for problem solving in a collaborative learning environment, both in theoretical studies and in real case projects with public or private organizations. Courses build on each other and may apply different steps of the ABCD process, having in common the use of visualization of co-created models, and an emphasis on facilitation and continuous peer feedback. In this way, students learn from each other's models and collectively go through a transformative learning process [34]. Another two-year, master's program in sustainable product innovation also applied strategic sustainability perspectives in courses on sustainable product system development [35]. Similar to the previous program, students here utilize simplified forms of CLD in their teams to describe various sustainability issues in a product innovation context. In this way, students together created cause- and effect models inside the framing of an ABCD process to identify the characteristics of a sustainable product solution concept, and the parameters that need to be considered in order to realize that concept. The student teams presented their system models to each other and received feedback from other students in several iterations [33].

Similarly, engineering students in a bachelor's level course on innovative and sustainable product development recently used simplified versions of the above-mentioned GMB workshop method. Here, the students were, just like the workshop participants, provided with a fictive sustainable design problem and asked to describe between which of the predefined sustainability criteria indicators and requirements they could find relationships. For this purpose they were also provided with templates that guided them to the GMB process, in which they (i) mapped which factors were related; (ii) used RBDs to describe the relationship; and (iii) modeled the relationships in a CLD; and (iv) annotated whether new, previously unknown factors were required to describe it. Thereafter, the students, who were divided into teams, presented their system models to each other. The resulting models showed that the same design problem was interpreted differently by the students as they had identified different relationships and described those in various levels of detail. The discussion afterward was recorded in a bullet-point format at the whiteboard. Figure 3 shows an excerpt of an example CLD, which could be produced during a GMB exercise.

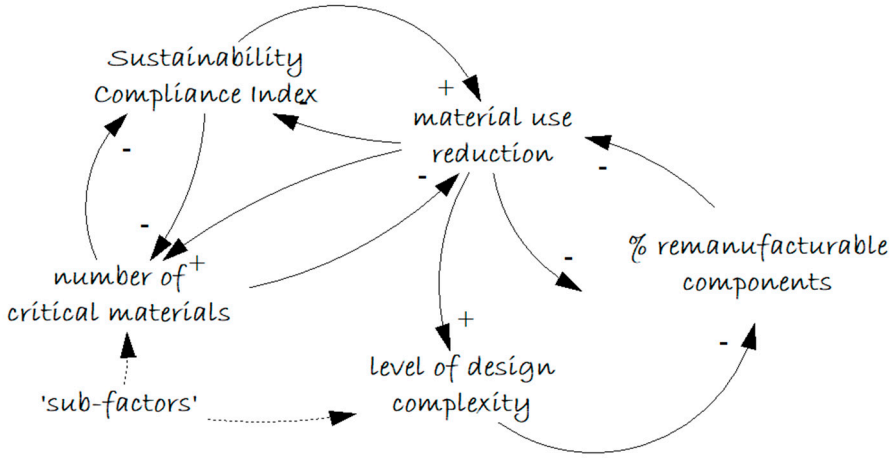

Figure 3. Excerpt of a causal loop diagram, reproduced from an in-class group model building exercise.

The mode of GMB application in the course activities, together with student feedback, has been to analyze the potential contribution to sustainability competency development and type of learning.

Analysis of Case 4

Case 4, like Case 1, applied the first three steps of the general GMB process to support a strategic planning process toward sustainability. Here, simplified CLDs were used to map an organizations' or a product concepts' behavior in a future sustainable scenario as well as current misalignments to sustainability principles in the current, and including key stakeholders and actors. Sustainability criteria are hence derived from the sustainability principles, i.e., step A, and current challenges and opportunities were discussed with support from the CLD model, i.e., step B. In this way, the GMB exercises may contribute to the key competencies of systems thinking-, anticipatory- and normative thinking.

This may be reflected in student feedback. For instance, statements about the GMB exercise in the engineering course at the bachelor level included 'same design problem was interpreted differently', 'different relationships', and 'various level of detail', which were associated with variables, sub-systems, structures, etc. from the systems thinking competency, and with dependency from the anticipatory competency. The exercise also used brainstorming, RBDs, and CLD to encourage qualitative systems mapping and scenario modeling. Another sign of systems thinking was that students found it easy to intuitively detect relationships between various sustainability criteria and design requirements, but more difficult to identify the feedback behavior, as it may occur with time delays. Some signs of concepts relatable to the strategic competency were found in comments such as 'they found themselves drawing models where sustainability improvements sometimes were aligned with the traditional requirement'. The learning activity might have contributed to accommodative learning, similar to in Case 1, as the exercise was limited to one session aiming to increase collective understanding rather than for planning activities.

In surveys with alumni from the 1-year master's program, around 95 percent of the respondents (128 out of 142 entered, 50 percent response rate) reported that their abilities in systems thinking, critical thinking, futures-oriented thinking, strategic thinking, and interdisciplinary thinking had increased. Collaboratory and leadership-oriented skills had also been improved, and they had developed personally in terms of self-evaluation, empathy, deal with complexity, and uncertainty, to mention some aspects. The same survey indicated that students experienced a transformative learning experience as the program allowed them to change carrier paths. Whether the use of GMB activities alone contributed to the development of these competencies, and perhaps transformative learning, is however unlikely as the program combines so many pedagogical approaches [34].

4. Discussion

The analysis presented in this research should be considered as a contribution to the discussion on useful methods for teaching and training that aims to foster learning for sustainability. To explore the potential of GMB as a means to help foster learning for SSD, this research developed a reference model against which four cases of GMB application in research and education for SSD were assessed. The reference model outlined the main content and purpose of the steps in the FSSD's ABCD-process for strategic planning toward sustainability and the five steps of a general GMB process, key sustainability competencies, and characteristics of learning for sustainability. Material from the different cases was assessed using qualitative content analysis, allowing the potential effect of each GMB application on sustainability competency development and learning to be discussed. The results of this analysis can be seen as an invitation for further and more detailed investigation of how GMB may be used to leverage the competencies and types of learning that are necessary for strategic sustainable development planning. The outcome of the analysis is summarized in Table 2 and reveals that that not all case applications deployed the full ABCD-process, nor all the steps of the general GMB process. The table, however, indicates an alignment between the number of steps applied in the general GMB process, the steps in the ABCD-process, and the type of learning. This indication suggests that the first three steps can support Steps A and B, i.e., mapping and describing and defining the key characteristics of the sustainable scenario as well as current causes to un-sustainability. All five steps can be organized so that they also contribute to Steps C and D, i.e., the strategic decision-making in which new policies and plans are developed, selected, evaluated, and refined.

Table 2. Overview of the cases' potential contribution to sustainability competencies, types of learning, and applied steps in the group model building process and process for strategic planning toward sustainability.

Case	Contribution to Sustainability Competencies	Type of Learning Loop	Type of Learning	'ABCD Steps'	GMB-Steps
1	Systems thinking, Anticipatory, Normative, *Interpersonal*	Single	Collaborative, accommodative	AB	1–3
2	Systems thinking, Anticipatory, Normative, Strategic, *Interpersonal*	Double	Collaborative, accommodative	ABCD	1–5
3	Systems thinking, Anticipatory, Normative, Strategic, *Interpersonal*	Double	Collaborative, transformative	ABCD	1–5
4	Systems thinking, Anticipatory, Normative, *Strategic*	Single	Collaborative, accommodative	AB	1–3

4.1. Potential to Foster Key Sustainability Competency Development

Results of the case analysis suggest that deploying the first three steps of GMB within the framing of a strategic sustainability perspective may potentially contribute to three out of the five key sustainability competencies, namely, systems thinking, anticipatory competency, and normative competency. All case analyses showed that elements of these three competencies were used, and experienced, by the participants. *Systems thinking* competency development was supported through participatory workshops and qualitative CLD model building. Key concepts such as indicators, feedback, causality, and more, were discussed in multiple stakeholder perspectives including social, ecological, technological, and economic. The collaborative creation of CLDs may, in itself, also support the systems thinking competency as relationships between indicators for different stakeholder perspectives and domains, both social and ecological, are built into the same model. The *anticipatory competence* may be supported as CLDs allow dependencies to be discussed and visualized. Indication

of the contribution to this competency can be found in, for example, thee participant feedback in Case 4 where students mentioned how some sustainability impacts may occur with time delays, similar to the comments of participants in the workshop method in Case 1. Signs of contribution to the *normative competency* may be found in the use of normative sustainability constraints, i.e., the sustainability principles or sustainability criteria derived from the sustainability principles. Together with the collectively created CLDs as part of the GMB process, participants might be supported in describing shared goal scenarios and deviations from these scenarios that are present in the current system. For example, Case 2 used sustainability assessment as guidance to find 'win–win–win' scenarios for product designs from an ecological, social, and business perspective. These results are in line with adjacent findings, see, e.g., Ayers (2020) [34], who suggest that the sustainability principles can provide the normative constraints that may help students envision the implications of sustainability in a specific context. The GMB process might hence have the potential of helping students structure this exercise so that they reach the same understanding of these implications.

Two cases were applied for all five steps of the general GMB to support the execution of Steps C and D in the ABCD method for strategic planning toward sustainability. From the analysis of these cases, some indication of contribution to the *strategic* sustainability competency could be deduced. By simulating different pathways to the normative goal scenario using SD models, participants were given the opportunity to 'see' the impacts of the discussed decisions (Case 3) or optimization strategies (Case 2). This allowed them to discuss concepts such as strategy, transformation, viability, efficiency, synergy, and effects, to mention a few. Case 3 explicitly described how SD models contribute to policy and scenario testing as decision support to select a sustainable transport strategy.

Indication of contribution to fostering the *interpersonal competency* was more difficult to assess, but concepts such as collaboration, leadership, and motivation might be associated with all the analyzed GMB case applications. This can be researched further, and especially one of the master's programs in Case 4, see [34], might be the source of information for how to combine other pedagogical approaches together with GMB with this purpose in mind. Going through the full GMB process, which can also support Steps C and D, might also support in fostering the *strategic competency*, as the effects of decisions on the goal scenario are what was being studied. The interpersonal key sustainability competency might be supported through the participatory GMB process itself, but was not addressed in depth in this paper and could be researched further. For instance, adjacent research implies that signs of interpersonal competency were associated with the dynamics experienced by the group of students while undertaking a sustainability project [41].

4.2. Potential of Fostering Learning for Sustainability

With regard to the potential contribution to learning for sustainability, the table indicates that two final modeling steps of the GMB process inside the framing of Steps C and D might have the ability to contribute to double-loop learning cycles. As this is a key characteristic of transformative learning that is associated with learning for sustainability transitions, this is an interesting potential of GMB that could be worthwhile addressing in continued research.

While qualitative CLDs developed during the first two GMB steps allows for some collaborative learning, it does not require participants to select and experience the effect of decisions, policies, or strategies. CLDs may provide a good base for discussing these effects, but the quantitative dynamic simulation offers actual visualization of how different strategies might affect different stakeholder perspectives, that is, parts of the socioecological system. Therefore, Steps 1 and 2 of participatory GMB framed by the key sustainability competencies of systems thinking normative, anticipatory associated with Steps A and B of the ABCD process for strategic planning toward sustainability may contribute to accommodative, incremental learning *about* sustainability. Cases 2 and 3 show indications that the application of the full GMB process contributed to radically different decisions regarding product designs and transport systems being made, compared to a traditional situation. However, these studies

took place over long time periods compared to Case 1, and 4, which is a factor for double-loop and transformative learning, see, e.g., [8,21], and were not thoroughly addressed in this research.

In this way, it seems as if GMB, when framed by a strategic sustainability perspective, has the potential of fostering learning for sustainability at different scales depending on how many steps are utilized in the GMB process. However, the survey results discussed in the analysis of Case 4 revealed that students' felt that they had experienced transformative learning after having left their program, meaning that there are other pedagogical approaches that contributed to this, since only the first two steps of the GMB process, as defined in this paper, were used.

4.3. Limitations and Opportunities for Further Research

Aside from applying GMB framed by a strategic sustainability perspective, there are many other teaching methods and pedagogical approaches that can also contribute to learning for sustainability, which have not been discussed in detail in this paper. Examples include, but are not limited to, service-based learning, project-based learning, and social learning. Together, these can contribute to a learning progression, see, e.g., [18] and the co-learning required for transformative learning for sustainability transitions, see, e.g., [42], which in this research were associated with so-called double-loop learning.

This research has only started to explore the potential of the types of modeling and simulations used in the generic GMB process, combined with a strategic sustainability perspective, in order to leverage this type of learning. Other critical factors for transformative learning, besides the teaching methods as such, are participants feelings, emotions, and mindsets [43]. Some indication of changed mindsets may however be found in comments from case study participants, see, e.g., Case 2. Pedagogies must also be capable of providing a 'lived experience', as discussed in [42], for example, when resources do not allow double-loop learning cycles. The analysis did not distinguish in detail between organizational or individual learning, although the data in Cases 2 and 3 perhaps could qualify as an organizational learning assessment. Another limitation of this research is a lack of discussion on the external factors to the case study analysis results such as geographical context of GMB application, or participants prior knowledge and skills. As a final note, the case analyses were based on secondary data that were not collected with this specific study in mind. A new case analysis designed with this specific research question in mind in which primary data were collected and analyzed using the same reference model, would therefore be interesting from a research validity and credibility perspective.

There are hence many opportunities to continue researching the opportunities of using GMB as a method for sustainability competency development and to facilitate learning for sustainability, either in the form of training for practitioners, or in courses in higher education programs, and perhaps in combination with project based learning as a way to build a learning progression [18,34].

5. Conclusions and Outlook

This research aimed to contribute to the discussion on teaching methods that foster learning for (strategic) sustainable development. The potential of participatory GMB as a means for this purpose was explored. The guiding research question was *'in which way may group model building be used to foster learning that leads to competency for strategic sustainable development?'*. To address the research question, four cases in which GMB have been used in research and education within SSD were qualitatively analyzed. A reference model developed from theory on learning for sustainability and key competencies for sustainability, along with a strategic sustainability perspective, was used as the lens for the analysis. The results indicate that different steps of the general GMB process may have the potential to contribute to different degrees of learning and to different sustainability competencies. Fostering systems thinking-, anticipatory-, and normative sustainability competencies and accommodative learning may be supported by the first three steps of GMB framed by the strategic planning toward the sustainability process. In practice, this means that participants of the GMB activity together may build a causal loop diagram to illustrate dependencies between stakeholders in the

social and ecological systems and use this as basis for discussion for reaching a sustainable scenario. Fostering strategic sustainability competency as well as transformative double-loop learning could be supported by Steps 4 and 5 of the GMB process. Dynamic simulations allow for the potential effects of different strategies on the normative goal scenario, framed by the sustainability principles, to be visualized, which can allow learning from hypothetical scenarios.

Academia can use this research as input for continued investigation of how to effectively create decision support that builds knowledge and trust across disciplines, with the common aim of sustainable development.

Higher education can use this research as methodological inspiration in teaching sustainability to enable transformative learning for sustainability experiences in different course or program contexts, for instance, in planning course syllabi and course progression. Inspiration may be found in courses at the master's program in strategic leadership toward sustainability at the Blekinge Institute of Technology.

Organizations can use this research as a source for ideas on how to integrate sustainability into their operations and how to foster the critical competencies related to sustainability capability.

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