remote sensing

Letter

Advancing Learning Assignments in Remote Sensing of the Environment Through Simulation Games

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Abstract: Environmental remote sensing has faced increasing satellite data availability, advanced algorithms for thematic analysis, and novel concepts of ground truth. For that reason, contents and concepts of learning and teaching remote sensing are constantly evolving. This eventually leads to the intuition of methodologically linking academic learning assignments with case-related scopes of application. In order to render case-related learning possible, smart teaching and interactive learning contexts are appreciated and required for remote sensing. That is due to the fact that those contexts are considered promising to trigger and gradually foster students' comprehensive interdisciplinary thinking. To this end, the following contribution introduces the case-related concept of applying simulation games as a promising didactic format in teaching/learning assignments of remote sensing. As to methodology, participating students have been invited to take on individual roles bound to technology-related profiles (e.g., satellite-mission planning, irrigation, etc.) Based on the scenario, stakeholder teams have been requested to elaborate, analyze and negotiate viable solutions for soil moisture monitoring in a defined context. Collaboration has been encouraged by providing the protected, specifically designed remoSSoil-incubator environment. This letter-type paper aims to introduce the simulation game technique in the context of remote sensing as a type of scholarly teaching; it evaluates learning outcomes by adopting certain techniques of scholarship of teaching and learning (SoTL); and it provides food for thought of replicating, adapting and enhancing simulation games as an innovative, disruptive next-generation learning environment in remote sensing.

Keywords: environmental monitoring; remote sensing; simulation game; scholarship of teaching and learning; SoTL; learning; soil moisture; food security

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1. Remote Sensing Higher Education and Simulation Games

Remote sensing is the fastest growing area in geographical sciences with increasing interdisciplinary approaches, including physics, biology and data science [1]. As to the state of the art of related technologies and data policies, remote sensing provides manifold implementation options, both in science and practice [2,3]. In order to design future data products and services relying on remote sensing data, the understanding of complex environmental processes will be essential. In this particular vein, the key learning objective is to raise awareness of the complexity of interdependence between remote-sensing signals and occurring ambiguities with land-surface components [4,5].

Provided that remote sensing is dealing with technological innovations, learning assignments must adequately correspond and respond to these developments. Right now, teaching in the field of remote sensing is still attributed with inert/non-productive knowledge which is considered highly specialized and technical, but hardly enables exchanging views across disciplinary borders. Broadening this scope, however, is urgently required, since most challenges in the area of remote sensing application are gradually turning heterogeneous, i.e., involving different disciplinary approaches that reach beyond its own. In order to ensure cross-cutting learning, corresponding techniques or formats are very promising [6,7].

Simulation games constitute a relatively novel and innovative means of teaching and learning to a) access content that aims beyond disciplinary contexts, and b) stimulate interaction among participants [8–13]. Thus, the interdisciplinary or cross-cutting nature is inherent to uno-actu assignments that are representative of simulation games, inter alia [14]. They "originate from strategic, scenario-based planning; they are playful, interactive and participatory methods or formats designed to train multiple competences, ranging from simple, instantly performed role plays to complex simulations lasting several days or weeks. Simulation games either focus on prototypal imitations of real/existing situations or events (simulation), or address archetypal scenarios of fundamental problems or conflicts (planspiel). In academic contexts simulation games become increasingly popular and relevant. They appeal to our gaming nature as homo ludens; they call for an essential academic freedom to act; and they provide novel, innovative and adaptive learning arrangements" [15].

Scientific publications discussing teaching and learning strategies in remote sensing higher education are rare. Not a single scientific publication presenting and discussing the application of simulation games as didactic format in remote-sensing teaching and/or learning is available. Requesting within the Web of Science Core Collection database easily validates this situation with public transparency [16]. A request for the past five years (2015–2019) using remote sensing teaching as key word selects 93 articles (request in December 2019) and, out of these, only 18 studies could be selected to address the topic. Twelve of the articles are conference proceedings; six are journal articles. All 18 publications were cited 42 times (without self-citation) relating to different fields of research (cf. Figure 1). Applying remote sensing higher education as selection criteria, 70 articles were selected from Web of Science Core Collection including three articles of the first data base request (remote sensing teaching as a key word). Given the need to advance teaching and learning strategies of higher education in remote sensing, there is a manifest lacuna in terms of scientific literature. Regarding recent and future innovations in earth observation technology, teaching contents are increasing tremendously; they are highly diverse as a result of research scope and remote sensing data application, e.g., hydrology, agriculture or social sciences [3]. Furthermore, facilitating creativity together with students is important to advance remote sensing-based monitoring solutions and gain advancements in environmental application.

In software development and industrial product development, agile management structures or Design Thinking are more and more implemented and accepted. Training students in a) creativity and b) critical thinking skills is a major goal in higher education [17]. Simulation games provide a viable didactic approach of addressing environmental monitoring challenges; due to the flexible design they stipulate a promising option for teaching and learning [18–23].

In order to provide evidence for the value-adding of introducing simulation games in teaching remote sensing, the study course particularly targeted for Master's students in the field of remote sensing, e.g., geo-information technologies, has carefully been analyzed. The notion was to provide students a novel, interdisciplinary and challenging learning environment that considerably differs from conventional assignments. Expectations accommodate, inter alia:

- more personal motivation and individual involvement;
- more exploratory acquisition of relevant skills and knowledge; and
- more practical relevance for the decisions made and obtained results.

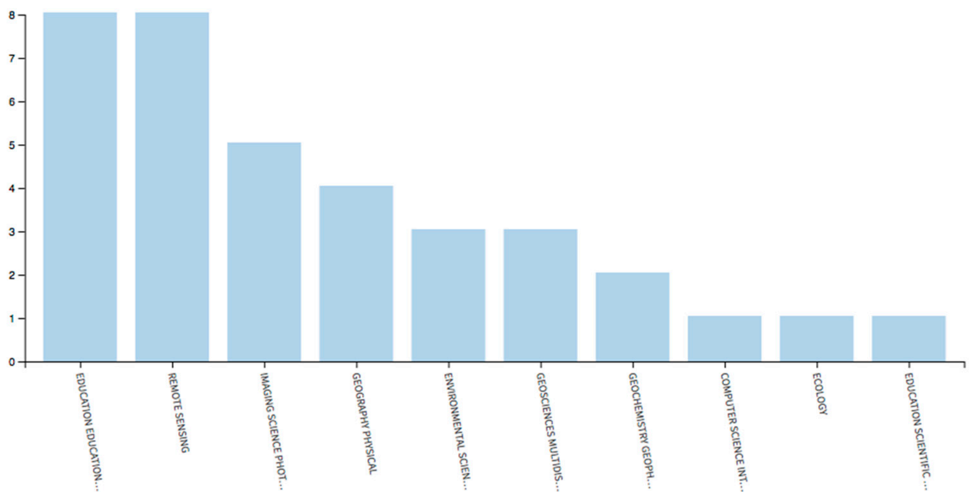

Figure 1. Representation of research areas of 18 selected publications discussing remote sensing higher teaching from 2015–2019. The Y-axis indicates the number of publications. Selection on the basis of a Web of Science database request using "remote sensing teaching" as selection criteria.

Contributions of this study include:

a) the presentation of the remoSSoil teaching concept and learning objectives to incorporate multi-source remote sensing and in situ data for soil moisture monitoring at regional scale (Section 2.1),
b) the classroom set-up and evaluation procedure (Section 2.2),
c) results and a comprehensive discussion of prospects and concerns for application of simulation games in teaching and learning remote sensing of the environment and the transfer of remoSSoil, in particular (Sections 3–5).

2. RemoSSoil Set-up of Sensoria Nutritiva

2.1. Teaching Concept and Learning Objectives

Since remote-sensing applications are to persist in highly competitive contexts as marketable solutions, it is pivotal to expose scholars/students to real-world scenarios already throughout their studies. This includes implementing both scientifically proven methods and those constrained by financial resources, lack of knowledge or given property rights. To this end, remoSSoil represents a customized, realistic simulation game that provides training opportunities of learning and applying selected methods in the field of multi-source remote sensing and in situ data integration at small scale, i.e., on a regional level of application. The key teaching objective of remoSSoil is to trigger students' creativity for designing a remote-sensing-based soil moisture monitoring concept that addresses agricultural requirements. In view of the fact that the simulation game touches upon a remote-sensing topic, at least one stakeholder group is required that provides basic knowledge in the field. In general, remoSSoil can be performed, adapted and replicated throughout all disciplines in the area of environmental sciences. Students of business management may collaborate, above all.

Based on a scenario and following the strategic approach of monitoring soil moisture at regional scale, a range of technologies of remote sensing (active and passive microwaves, multi- and hyperspectral data and thermal observation) has been considered according to their pros and cons. For this purpose, participants have been requested to take on roles connected to technology-related profiles in order to elaborate viable solutions for soil moisture monitoring by co-operating within a specifically designed, access-protected remoSSoil-incubator environment.

The scenario is divided into three consecutive parts. First, in the initial stage the situation in Sensoria Nutritiva is described, a fictitious region that suffers from a food crisis due to failed crops.

Millions of people starve themselves. There are massive protests over weeks that threaten the internal security of the country. Experts from the world food organization directly correlate soil and climate conditions with plant growth. Half of the surface is reserved for agricultural purposes; the rest consists of grassland, forest and fallow land. The proclaimed food security appears to be at stake. Resulting impacts on the society, economy and political situation would be incalculable. Second, in the interacting stage an exclusive remoSSoil incubator is introduced as means to prevent Sensoria Nutritiva from prospect food crises by providing the population with groceries and stability. Such an innovative think tank, funded by public authorities and private-sector stakeholders, aims at contributing to the strategic design some significant monitoring system while taking into account:

1) state-of-the-art technologies and methods of remote sensing for analysis and assessment;
2) scientifically sound correlations between soil quality and plant growth; and
3) concise recommendations and implementation guidelines based on economic and political feasibility.

Third, in the decision-taking stage participating stakeholders are requested to set up a concerted road map that reflects practical steps of designing and implementing a monitoring system of soil moisture for food security in Sensoria Nutritiva. An expert panel is established as part of the remoSSoil incubator to reconcile diverging interests and approaches, and to finally accord in a binding agreement.

The following set of stakeholders (six in total) has been pre-designed, randomly distributed, introduced, and defining relevant profile characteristics:

- satellite manufacturer (two participants): develops and runs up-to-date satellites and remote-sensing devices as global market leader; provides low up to high spatial resolution in order to data application from local to global scale; enables a varying data availability ranging from rarely to frequently, since natural processes take place at different moments in time; provides data with base correction only, since further processing differs according to range of use;
- ministry of environment (two participants): represents a public-sector institution with administrative capacity but limited level of creative potential; provides a low-scale spectrum of remote-sensing data, as novel approaches have not yet been integrated into the authority's data services; accomplishes a rather poor data availability, because of costs and limited human resources; data, however, are displayed in a very precise way due to the fact that those data are used for decisions of the agency that need to be legally effective;
- agricultural association (one participant): serves as strong lobbying representation of agricultural companies and is highly interested in usable data on soil quality; provides a database of in situ field records and soil maps, and runs a privately-owned observation ward; requires a high data resolution, since agricultural land can be used efficiently and more effectively in both economic and ecological terms; is dependent from a high density of data due to preparing the soil during the growth period with fertilizers and irrigation; is in need of precise data for precision farming; and
- irrigation company (one participant): performs as an agile, medium-sized company that is specialized in product development of innovative irrigation systems; requests an extremely high spatial data resolution due to the fact that irrigation systems must be installed with utmost precision; is demanding for real-time data given the vertical and horizontal distribution of precipitation as a function of initial soil moisture; requires precise data due to efficient use of water resources.

Participants of the remoSSoil simulation game are required to:

- actively co-operate throughout all levels of game design;
- compile a policy paper and coherent strategy paper based on the given profile characteristics;
- formulate an account of proceeding on the remoSSoil incubator from the role's perspective;
- conclude with an in-depth paper of reflection; and

- draft a poster with results and a road map.

The critical learning outcome is to raise awareness of the complexity of practically applying advanced remote-sensing techniques through correlating soil moisture content with agricultural productivity. Put differently, participating students are encouraged to study the signal interactions and to deliberately decide what is relevant and how it can be integrated into a monitoring concept. Learning objectives comprise of:

- adapting aspects of multi- and hyperspectral remote sensing, including effects of temporal, spectral and spatial resolution on application;
- studying passive and active microwave data and its sensitivity to soil moisture and vegetation properties;
- assessing the value of thermal infrared data, its application to retrieve microwave emissivity and as a source for soil moisture proxy;
- adopting a ground truth component as key for thematic application;
- considering aspects of operational monitoring, i.e., needs of the temporal consistency of temperature and passive microwave observations, spatially explicit vegetation and soil data;
- understanding synergies and complementing factors in order to gain benefits from multi-source remote sensing analysis; and
- getting in touch with general processing steps for different remote sensing data products.

2.2. Classroom Set-Up and Evaluation Methods

Based on a deliberately chosen, disciplinary approach, participants of the tailor-made remoSSoil simulation game have been invited to join an innovative learning environment that is thoroughly scenario-based and designed according to predefined, consecutive stages (cf. Figure 2). The classroom set-up consists of an introductory flipped-classroom manual on simulation games as format, five face-to-face courses, an e-teaching platform for resources and e-tutoring, and two individual, optional consultation periods per group/stakeholder. Encouraged to opt for a pre-defined stakeholder status, teams have been created by chance through a lottery. However, to a certain extent both individual and technical role-playing preferences have been acknowledged. Participants have been requested to provide a convincing and sound role profile that has subsequently been presented in a concise and focused manner. Related positions have been underpinned by a policy paper due to be published in conjunction with the profile presentation. This publicly accessible information stipulates the contextual grounds for activating stakeholder interaction in a complex, situated learning environment [24]. According to the scenario, stakeholders have been requested to adopt a concerted, ready-to-implement road map for soil moisture monitoring. Negotiations have taken place within the protected area of an incubator that encourages participatory decision-taking through actively taking into account diverging stakeholder interests. Results have been presented in a separate session, followed by documenting results as artefacts, both cumulative and summative (e-portfolio), summarizing findings (poster) and evaluating learning outcomes (e-evaluation).

Presuming that learning assignments in the remote sensing of environment might be enhanced through applying simulation games, a progressive evaluation methodology has been applied in order to monitor and assess different stages of evolving expertise vis-à-vis soil moisture monitoring of remote sensing. This kind of customized progress monitoring involves both learners' and dual facilitators' perspectives, including reflecting upon professional profiles (remote-sensing specialist and business-trained simulation game developer), quadruple profile-related assignments, and the weekly workload/dedication (approximately four hours each).

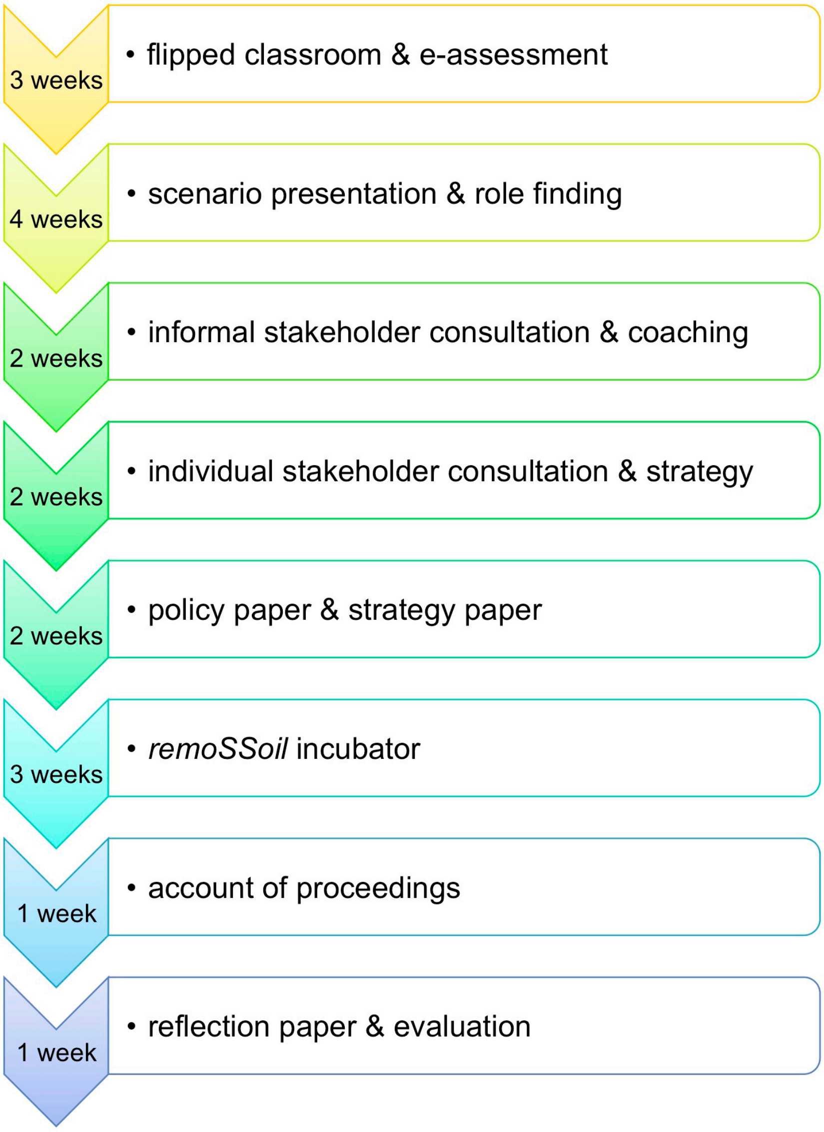

Figure 2. Stages of the remoSSoil simulation game.

Simulation games yield cumulative outcomes due to an explorative and interactive design. Thus, learning outcomes and impacts need to reconcile the dynamics of the simulation with assessment techniques of knowledge and abilities. This perfectly coincides with successive learners' portfolios or e-portfolios, respectively, in this very context [25,26]. Accompanying research is framed in the context of collaborative scholarship of teaching and learning (SoTL) [27–31]. It relies on principles of qualitative content analysis through questionnaires, participatory observation, work-in-progress presentations, e-portfolio data and narrative, ad-hoc and first-hand accounts [32–35], in order to elicit valuable, directly applicable information for tendency-finding analysis [36–39].

Qualitative data have been collected—given the explicit consent of the participants—at three different stages/intervals: a) at the beginning after the introductory session (work-in-progress presentations and narrative, ad-hoc and first-hand accounts [40–42]), b) during the consultation process (participatory observation and narrative, ad-hoc and first-hand accounts [41,42]), and c) at the end (work-in-progress presentations, e-portfolio data and narrative, ad-hoc and first-hand accounts [40–43]) of the simulation game. Both participants and facilitators responded to the identical following four questions:

1. What are your most significant findings?

2. What relevance do these findings have?
3. How do these influence your further strategy?
4. How do you cope with resulting challenges?

3. Outcomes

3.1. Adopting the Simulation Game Scenario as Novel Learning Environment

The first progress monitoring was conducted in the course of the role-finding session after having presented their respective stakeholder profiles [40]. Taking a look at the most significant finding, participants quickly managed matching the scenario with their individual role profiles by themselves, in most instances; few felt some unease and confusion with the format. Some appreciated the trained creativity that appeared to be lost in some occasions of their studies. Facilitators appeared to be convinced both of the format and the performance, particularly in terms of articulated scope for development; however, improvements were suggested for enhanced coaching opportunities and interior design of the workshop venues.

In view of resulting implications, a couple of participants addressed the excitement factor that drives them to investigate further for competitive arguments and individual strategies; some feared that their technological knowledge would be underrepresented as a result of the format. Facilitators quickly optimized their understanding of the format and their role as more coaching than instructive. Concerning the strategy-driven aspect, all participants clearly stated their full commitment and general orientation for the continuing course of the format, at the same time. This includes the perceived need to elaborate positions further, to foster alliances among stakeholders and to be personally held accountable for data and duties to be delivered on time. Facilitators encountered the need to provide more platform-based coaching opportunities and more spatial visualization of the scenario. In general, no major adaptions were envisaged for the next stage. In terms of appearing challenges, participants raised various issues ranging from active listening to more targeted research, from in-depth scenario reflection to internal responsibilities' assignment, from intuition to focused stakeholder analysis, and from agile reactions to planned strategies.

To sum up, the simulation game scenario serves as a novel learning environment to enhance students' responsiveness, commitment and accountability [44–47]; simultaneously, it promotes activating citizenship across the curriculum [48].

3.2. Drafting Stakeholders' Ambitions as Creative Learning Process

The second progress monitoring was assessed subsequently to the policy-defining and strategy-developing stage, and prior to the negotiating phase of the remoSSoil incubator [41]. With regard to the most significant findings, participants truly appreciated changing perspectives as constituent parts of their role functions.

Apparently, the need for creative thinking triggered both communication skills and eagerness of exploring required content (link to remote sensing specific learning objectives) to similar extent. This obviously led to shifting priorities from technical issues towards professional bargaining techniques, including monetary restrictions and in-depth strategizing. Appropriately documenting policies and strategies was considered key to negotiation success. Coaching and/or consultation opportunities were extensively made use of.

In terms of resulting implications, technical expertise was regarded poor/insufficient to keep up with bargaining requirements. Such ambivalence created both unease and challenge to resolve existing technical uncertainty and shortcomings interactively. In this respect, the simulation game approach was perceived as refreshing, as a result of purposefully deviating from standard designs of teaching and learning.

To conclude, apparently, soft skills of interpersonal communication and negotiation played the pivotal role of drafting ambitions, i.e., expertise was finally obtained as a result of a broker-like process among stakeholders. Gained knowledge of ground truth information and its value on soil moisture product quality was key in the integrative bargaining. Aspects of ambiguities in soil moisture remote sensing were discussed and considered by making use of the data combinations (as applied in real scientific environment).

3.3. Accomodating Didactics-Based and Content-Related Learning Needs

The third progress monitoring has been deduced from the e-portfolio that has been compiled by the stakeholder teams of the simulation game [42,43]. Beyond the simulation game approach itself, participants very much appreciated the exploratory set-up of negotiating contents in a rather spontaneous and interactive manner. Defining their role profiles accordingly was considered an asset in order to cope with multi-party perspectives in the course of managing the scenario. Applying obtained didactical insights to real cases or similar projects was regarded as promising; this intention is most related to the ambition of bringing together diverging interests to a common denominator. New subject matters arose that led to innovative momentum and enhanced stakeholder commitment, resulting in proper profiles with positions, strategies and corporate designs.

Further development is needed for informational flux in terms of framing the scenario with key parameters for more in-depth analysis and more to-the-point interaction. Food for thought was articulated on the content side; more technical references could have been integrated into remote sensing, including more focused experts' talks, individual research, proper soil moisture maps etc. This may contribute to the full potential of the format unfolding. Last but not least, workload, working styles/morale among team members and assessment criteria remain persistent hot-potato issues.

Take-home messages for the participants are both process-related and content-wise. First and foremost, both the pro-active element and negotiating aspect of the simulation game approach were highlighted positively, including the steps of getting there, e.g., through carefully analyzing, refined strategizing, defining, presenting and implementing positions, communicating and convincing others, making conflicts visible and coping with diverging ambitions, and compromising reliably. Soft skills and abilities were trained, such as empathy, change of perspective, ambiguity tolerance, leadership, facilitation or teamwork. Fortunately enough, the fun and creativity factor was mentioned, too.

In a nutshell, from a content perspective, the simulation game in remote sensing by and large met the learning need of facilitating acquiring profound knowledge in an interactive and multi-level decision-making environment. The stakeholder set-up initiated the scientifically based discussion on multi-source data integration and aspects of temporal, spectral and spatial resolution due to application and data management. As to didactics, the simulation game made a meaningful contribution to more applied learning instead of lengthy theory; viable, multi-lateral solutions were considered more promising, interestingly enough.

4. Prospects and Notes for Simulation Games in Teaching and Learning Remote Sensing of the Environment

Recalling the initial question of how simulation games may contribute to learning outcomes, it can be stated that they do comprise positive effects on the exploratory acquisition of competences by:

1. recognizing distinct creative leeway in the field of soil moisture monitoring using satellite remote sensing (responsiveness, commitment and accountability);
2. making effective use of obtained expertise vis-à-vis soil moisture remote sensing (broker); and
3. strengthening collaborative environments by addressing face-to-face communication in the informed/qualified field of soil moisture monitoring of remote sensing (interaction).

Notes are related to the need of experienced teachers with advanced communication skills on the one hand, and providing a broad knowledge in remote sensing methodology and application on the other hand. The application of simulation games is limited to small student groups, as each stakeholder should have at least two members (students). To support continuous thinking and learning, activation is suggested during the self-learning periods. A supporting e-teaching environment is recommended by the authors. As each student group provides individual properties in remote sensing knowledge, communications skills and intrinsic motivation of the learning process is different. Here, the creative interaction of the teachers can adjust the direction to the learning objectives by initiating external events. As an example; if the stakeholder groups only addressing multispectral satellite data, an event (i.e., data downlink failure) could be communicated to guide them to microwave observations and gain appropriate knowledge.

Simulation games as didactic methods can be applied to each aspect of remote sensing. This might include sensor and mission planning, algorithm development including requirement engineering from various stakeholder perspectives, development of various information products and services, i.e., to assess carbon exchange, biodiversity, crop rotation, water quality assessment, and soil health monitoring. The simulation game method provides excellent prospects to increase interdisciplinary contents in remote sensing teaching. Teaching and learning scenarios may be established, i.e., for biodiversity assessment, landscape and urban planning, sea and lake water pollution and quality monitoring, and carbon-stock monitoring.

5. Conclusions and Future Perspectives

Showing promising motivational effects on learning outcomes, this study of scholarly teaching makes a significant and innovative contribution, since it presents the transfer of simulation game methodology into remote sensing teaching and learning in higher education [6,7]. At first glance, simulation games enable distinguishable capacities of creative thinking or designing; they facilitate communication processes among internal and external stakeholders, including potential authorities and the private sector, e.g., providing future-oriented concepts of biodiversity or climate adaption of green infrastructure. In this respect, the fit between the target audience (participating students), lecturer/facilitator and learning assignment is considered critical in terms of communicative styles or teaching habits, in order to generate positive learning outcomes on either side. For instance, if the teaching-learning-format is inconsistent with the mode of personal interaction, participants are prone to be emotionally lost due to being addressed in a non-authentic, less concentrated manner. This can be resolved by purposefully inviting lecturers from different units/departments or universities, even for joint sessions, in order to address a range/diversity of didactic formats. In order to provide manageable mobility and to ensure viable implementation, e-teaching components are to play a pivotal role in communication and beyond.

The increasing availability of e-teaching platforms, including communication functionality, paves the way for new class design and supervision. Learning materials, e.g., tutorials and self-assessments can be provided. Virtual classrooms can be applied for meetings and consultation. A main advantage for using an e-classroom may be the geographic independency which allows the collaboration between universities, universities and public agencies and international experts from industry and science, for instance.

Applying simulation games to different remote sensing monitoring topics might be an essential asset to address interdisciplinary teaching and learning in higher education. Simulation games can be applied to scholars from different universities of the same discipline or by incorporating a range of disciplines. Making use of interdisciplinary set-ups of mixed teams, mixed methods and mixed academic origins/notions is highly appreciated. They open unprecedented horizons to more collaborative teaching, including exchange of scientists and interactive lecture formats from various institutions. This enables the provision of highly procedural, up-to-date knowledge and methods, which are hardly manageable through series of single lectures, due to short turnaround cycles in remote sensing and environmental modelling. The challenge is to establish and design qualified coaching and consultation options, since those are pivotal in order to create sufficient drive and commitment. Interestingly enough, comprehensive e-learning activities are of minor importance.

The very fact that applying simulation games in assignments' yield learning outcomes/effects is undisputed due to empirical evidence through systematic assessment [22,23,44,49,50]. However, there is scientific potential to assess learning effects of scholars in the particular field of remote sensing by systematically comparing assignments of gaming with classical techniques. The proof is yet to come; the first steps are made.

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