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Communication tools and their support for integration in transdisciplinary research projects

Cornelia Fischer[1], Verena Radinger-Peer[2]✉, Larissa Krainer[3] & Marianne Penker[1]

This study investigated how different communication tools support integration in transdisciplinary research. Ten digital and analogue tools with different communication directions and degrees of participation were tested in a 3.5-year transdisciplinary research project. Based on an exploratory operationalisation of the social-organisational, cognitive-epistemic and communicative dimensions of integration, we compared the tools' integration support as perceived by 80 practitioners, 6 scientists and 3 integration experts. The multi-methods approach involved three surveys at different project phases, an ex-post poster assessment and interviews. The study showed that a variety of tools can serve diverse actors' needs with varying preconditions and can play a supportive role for integration. Throughout the research process, the project website was identified as the central information platform for all groups. A living document in the form of a large hand-drawn poster and sketchnotes provided quick and understandable overviews and were particularly relevant for the communicative and the social-organisational dimension of integration. Digital videoconferences performed best in the cognitive-epistemic dimension and were found to be effective for information exchange, while online voting, emails and minutes were perceived to be less relevant. The involvement of integration experts with diverse communication and visualisation skills can support adaptive, context-specific and dynamic choices of communication tools, making project outcomes accessible to a variety of actors in a timely and transparent way throughout the project. The communication tools that were perceived by the actors to be most supportive were those that used visual and textual sign systems and facilitated a strong group identity. Therefore, we conclude that future research should include and operationalise a fourth, *emotional* dimension of integration.

[1] Department of Economics and Social Sciences, Institute of Sustainable Economic Development, University of Natural Resources and Life Sciences, Vienna, Feistmantelstraße 4, 1180 Vienna, Austria. [2] Department of Landscape, Spatial and Infrastructure Sciences, Institute of Landscape Development, Recreation and Conservation Planning, University of Natural Resources and Life Sciences, Vienna, Peter-Jordan-Straße 65, 1180 Vienna, Austria. [3] Faculty of Social Sciences, Department of Media and Communications, University of Klagenfurt, Universitätsstraße 65–67, 9020 Klagenfurt/Wörthersee, Austria. ✉email: verena.radinger-peer@boku.ac.at

Introduction

In transdisciplinary research, scientists from different disciplines and practitioners with very different backgrounds and information needs join forces to explore complex societal and ecological problems (Adler et al., 2017; Bammer et al., 2020; Bergmann et al., 2005; Bernstein, 2015). In these target-oriented collaborative knowledge production processes (Pohl et al., 2021) one key is integration, understood as "an open-ended learning process without predetermined outcomes" (Pohl et al., 2021, p. 22). Integration—as a sub-process of transdisciplinary collaboration—can occur in all phases of a transdisciplinary project. The intensity, form and mix of how scientists and practitioners engage at different stages of transdisciplinary projects vary, and there is no single approach to integration (Enengel et al., 2012; Mobjörk, 2010; Pohl et al., 2021; Wang et al., 2019). It describes the act of incorporating, combining, synthesising or bringing together different perspectives and approaches to problem-solving (Polk, 2013), and in a broader conceptualisation includes cognitive-epistemic, social-organisational and communicative dimensions (Jahn, 2008).

Integration in transdisciplinary research depends on the design and maintenance of transparent and structured communication processes (Aenis, 2010; Bagnol et al., 2016; Kushnir, 2021; Robasky et al., 2020; Wang et al., 2019; Wickson et al., 2006) and communication at eye level between all actors involved (Kalmár and Stenfert, 2020; Krainer et al., 2014). Open and inclusive communication fosters information sharing, mutual understanding and collaboration (Fleming et al., 2021; Kushnir, 2021), and conscious communication is important for integration (Bergmann et al., 2010).

Several studies of transdisciplinarity highlight the importance of effective, balanced and targeted forms of communication supported by specific tools for realising the transdisciplinary approach (Aenis, 2010; Kushnir, 2021; Siew et al., 2016; Waag, 2012; Wang et al., 2018). Such tools, methods, and interventions can support integration and promote shared understanding between project actors (Bammer, 2017; Kalmár and Stenfert, 2020; Pershina et al., 2019; Pohl et al., 2021). Although many authors consider integration to be a core element of transdisciplinary research (Bammer et al., 2020; Becker, 2006; Bergmann et al., 2010; Hirsch Hadorn et al., 2008; Pohl et al., 2008), the support of communication tools (CT) for integration remains largely unexplored. So far, it is still unclear which tools support which dimensions of integration in transdisciplinary collaboration (Pohl et al., 2021).

We aim to address this research gap by comparing CT regarding their specific integration support in transdisciplinary research. We assume that integration in transdisciplinary projects depends on participatory methods and on personal communication (Kushnir, 2021), and is supported by CT. This paper focuses on the last of these and examines how CT support various dimensions of integration among diverse actor groups within a 3.5-year transdisciplinary research project. We follow Jahn (2008), who—as mentioned above and explained in more detail in the section "Communication tools in transdisciplinary research—state of the art and analytical framework"—distinguishes between (i) social-organisational, (ii) cognitive-epistemic, and (iii) communicative (Jahn, 2008). Although it is difficult to separate the different dimensions of integration (Peukert and Vilsmaier, 2021), Pohl et al. (2021) point out that effective integration requires the consideration of dimensions beyond that of knowledge integration.

CT address different actors (Bergmann et al., 2005, 2010; Defila et al., 2006), cover the need for mutual information exchange (Waag, 2012), and affect the engagement, empowerment and participation of practitioners (Thompson et al., 2017). Nagy (2020) suggests providing knowledge in multiple formats "where it can be enriched, adapted, and modified by actors there" (Nagy et al., 2020). In this study, we differentiate between practitioners, scientists and integration experts (for details see the section "Communication tools in transdisciplinary research—state of the art and analytical framework").

CT, as we define them in this paper, are helpful tools that support actors in overcoming challenges associated with divergent mindsets (Pershina et al., 2019). Tools like the ones we used in our project can (simultaneously) provide platforms for exchange (e.g., digital videoconferences, digital pinboards), enabling actors to collaborate. They can also serve as tools to organise the exchange of ideas and perspectives (e.g., project websites and orientation posters) and are multifunctional. Tools carry the meaning and determine the form in which the message is spoken, written, drawn or interpreted (Schophaus et al., 2004). There is neither a consistent use of the term "tools" nor a congruent idea of what objects are referred to as tools.

There are different ways of classifying communication and thus CT. Beck (2013) differentiates between types and forms of communication. Communication types include linear, unidirectional versus double or reciprocal mediation processes (one-way, two-way). Forms of communication are social, temporal, factual, spatial, semiotic and differentiation according to purpose (Beck, 2013). In our study, we use temporal (synchronous/asynchronous) and semiotic (auditory/visual/audio-visual/textual) distinctions of CT, but add the internal/external distinction from the field of organisational communication (Szyszka, 2013) To categorise CT according to their purpose in terms of participation, we distinguish three types (Enengel et al., 2012): informing (i.e., actors are informed about the research project), consulting (i.e., actors comment on proposals and contribute ideas and suggestions that can be considered in the research process) or co-producing knowledge and empowering (i.e., actors are involved, empowered and decisions are made together). We also differentiate the CT according to the degree to which they support group identity because the outcome of collaborative processes of knowledge production cannot be reduced to intellectual factors (Boix Mansilla, 2006; Pohl et al., 2021). Following Henry et al. (1999), we define group identity as the distinctive identity of a group as a collective. This identity includes the characteristics that distinguish one group from another, such as shared goals or sign systems (e.g., name of the group, logo). CT can support group identity by representing joint work and learning, interactions on issues and outcomes, links between actors, joint activities and shared challenges and solutions (Adelle et al., 2021; Boix Mansilla, 2006; Fromhold-Eisebith et al., 2009).

To sum up, our research focuses on the question: how do CT support the various dimensions of integration among different actor groups in a transdisciplinary research project?

The empirical case was the 42-month transdisciplinary research project "Empowerment, Self-Organisation and Regional Transformation—the model of the Club of Rome Region Carnuntum" (RLC 2040), where we introduced, adapted and studied several CT to support the different groups of actors despite frequently changing conditions caused by the COVID-19 pandemic. Our study looked at how actors perceived the CT in terms of supporting information exchange, providing overview and orientation in the project, communicating project results, creating a common group understanding, increasing the awareness of other perspectives, and integrating scientific and practical knowledge.

In the following sections we present the state of the art of CT in transdisciplinary research, our case study and how we compared different CT in terms of their support for the integration of

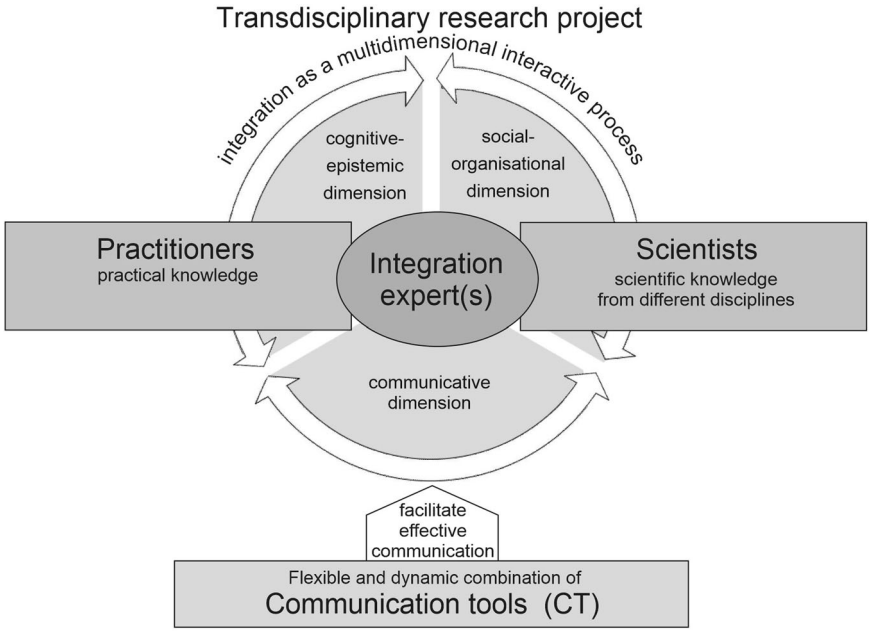

Fig. 1 Framework on the communication tools in transdisciplinary research projects. Communication tools play a supporting role in facilitating effective communication between different groups of stakeholders (practitioners, integration experts, researchers) and contribute to integration at the three levels of integration (cognitive-epistemic, social-organisational, communicative) (own illustration).

different actors. This paper is not a comprehensive presentation or evaluation of CT in general but focuses on the results and limitations of the CT applied in the "RLC 2040" project. We conclude by discussing how different CT support transdisciplinary integration for specific actor groups and reflecting on the selection, value, resources, and capabilities for applying CT.

Communication tools in transdisciplinary research—state-of-the-art and analytical framework

Despite the acknowledged importance of integration in transdisciplinary research, many authors emphasise that much remains to be learned (Pohl and Hirsch-Hadorn, 2006; Pohl et al., 2021). This gap also relates to tools to help actors identify their own and others' knowledge and thereby support integration (Pohl et al., 2021). Knowledge assets and mutual understanding can develop if the information is provided in an accessible and appropriate form (Bammer, 2013; Hasler, 2007). Therefore, a main criterion for the selection of CT is their suitability to bridge different bodies of knowledge and information (SCNAT, 2023). An additional selection criterion is the use of everyday language and the ability of the tools to promote common understanding, facilitate exchange between different ways of thinking and enable joint elaboration of knowledge and research results. CT enable effective communication during and outside of face-to-face meetings (see Fig. 1) and can provide information in discoverable and accessible ways (Robasky et al., 2020). They can support organisational work in the course of a project, create structures to improve exchange in the group (Boix Mansilla, 2006) and strengthen the integration process by visualising shared knowledge (Godemann, 2008; Kushnir, 2021). Structures and tools help actors feel involved (Fleming et al., 2021). In the literature, there are various references to different tools and their purposes. For example, visual products and tools facilitate interactions and thus encourage participation (Godemann, 2008; Lang et al., 2012). Platforms that facilitate learning and knowledge integration have the potential to build bridges between actors and foster trust through increased transparency (Godemann, 2008; Godemann and Michelsen, 2008; Misra and Lotrecchiano, 2018; Pennington, 2011; Potterbusch and Lotrecchiano, 2018; Robasky et al., 2020). Written summaries and digital artefacts reveal actors' interactions (Potterbusch and Lotrecchiano, 2018).

Digital CT provide the possibility to quickly adapt and enrich information (Härtel et al., 2015) or to support the generation, maintenance, exchange and use of knowledge independent of time and place (Fei, 2011; Probst et al., 1999). Digital communication channels support the exchange of information between actors (Härtel et al., 2015). They also enable the documentation of communication processes and their outcomes (Misra and Lotrecchiano, 2018) and support the management of knowledge processes (Fei, 2011). However, these channels are not the primary source of knowledge creation. Most tacit knowledge is too complex and experiential to be fully captured electronically (Fei, 2011). Furthermore, it is important to consider how to reach actors who are less familiar with digital technologies and applications, since these technologies and their applications require both the technical equipment for access and the skills of the actors (Leitner, 2018).

When designing the communication process, challenges arise such as adequately communicating unknowns, resource requirements, and assessing which information is relevant to which actors and to what extent (Bammer, 2013). Furthermore, different tools require different amounts of time and other resources.

Communication tools in transdisciplinary integration. As mentioned in the introduction, we refer to the three dimensions of integration differentiated by Jahn (2008): (i) social-organisational, (ii) cognitive-epistemic and (iii) communicative.

The social-organisational dimension concerns the management of the research process and team leadership (Defila et al., 2006; Hunecke, 2011; Loibl, 2005; Mogalle, 2001; Schophaus et al., 2004). The focus here is on CT support for the different groups of actors in terms of orientation and overview. Keeping diverse perspectives as well as the whole in mind supports collaboration between scientific disciplines and practitioners (Bammer et al., 2020; Nölting

Fig. 2 Orientation poster. The hand-drawn poster gave the project actors an overview on and orientation in the complex project process (own illustration).

et al., 2004). The cognitive-epistemic dimension involves recognising and linking various types of knowledge. CT can provide access to scientific knowledge from different disciplines and practical knowledge. Knowledge integration can only be achieved if actors can recognise (Pohl, 2011), communicate, and share their own knowledge (Härtel et al., 2015). This can lead to mutual learning and understanding processes (Burger and Kamber, 2003), which are addressed by the communicative dimension. It is important to represent and communicate knowledge linguistically and symbolically. In this way, elaborated knowledge can be presented in a comprehensible and connectable way (Hunecke, 2011; Jahn, 2008). Everyday language and the avoidance of scientific terms facilitate mutual understanding (Pohl et al., 2008); a common, linkable language improves integration (Krainer et al., 2014; Tress et al., 2007).

We assume that the three dimensions of integration, even if their boundaries are blurred, (Peukert and Vilsmaier, 2021), are well suited to capture the complex demands of integration beyond knowledge integration.

Communication tools supporting different actor groups. Transdisciplinarity literature refers to the context in which CT are used (Kushnir, 2021) and the need to prepare and present information in a comprehensible and target group-oriented way (Bagnol et al., 2016; Bergmann, 2008; Defila et al., 2006; Di Giulio et al., 2008; Härtel et al., 2015; Rowe and Frewer, 2000). Despite this, surprisingly little is written in the transdisciplinarity literature on how different groups of actors evaluate the support of different CT. Making the views of scientists and practitioners explicit is important for integration (Pohl et al., 2021; Radinger-Peer et al., 2022). In addition to actors from science and practice, intermediaries between the two groups have received particular attention in transdisciplinarity literature (e.g., Bammer et al., 2020; Hoffmann et al., 2022; Wiek, 2007). They manage the interface between science and practice and are supposed to promote integration. However, the naming and definition of this role vary widely, e.g., from communicator, mediator or intermediary (Hilger et al., 2021), epistemediator (Wiek, 2007), knowledge broker (Duncan et al., 2020; Hilger et al., 2021), process facilitator (Hilger et al., 2021; Pohl et al., 2010) to science consultant (Mogalle, 2001) or boundary spanner (Harris and Lyon, 2013). Like Bammer (2013), Bammer et al. (2020), and Pohl et al. (2021), we use the term "integration expert", who specialises in managing transdisciplinary integration (Hoffmann et al., 2022; Pohl et al., 2021). The integration expert designs, plans, implements and moderates the integrative processes, provides opportunities for integrative exchange and supports the emergence of integrated outcomes (Hoffmann et al., 2020). To accomplish these tasks, integration experts also need to think about how to "prepare, present and discuss results in a target group-specific way" (Krainer et al., 2014).

Case study

The Regional Development Association Römerland Carnuntum initiated the transdisciplinary research project "RLC 2040" together with two Austrian universities (University of Natural Resources and Life Sciences, Vienna (BOKU); Vienna University of Technology (TU Vienna)). For further information see Gugerell et al. (2023). The core of the project was the establishment of a deliberative regional Future Council as an advisory board for 30 municipalities located between the cities of Vienna (Austria) and Bratislava (Slovakia). In this paper, we do not consider integrative transdisciplinary methods such as visioning, scenario planning, serious gaming, or RegioLabs (Gugerell et al., 2023), which were implemented in face-to-face meetings for transformative learning in the framework of the "RLC 2040" project.

The actors involved could be assigned to two project bodies: The Future Council ($n = 80$), whose actors were practitioners, and the project team ($n = 13$), which organised and steered the project, managed the collaboration of the project bodies and the integration of scientific and practical knowledge. The project team involved scientists ($n = 6$) from the two universities, practitioners ($n = 4$) from the regional development association, and integration experts ($n = 3$). The last group included a consultant, a mediator and a scientist who contributed facilitation, mediation, project management, and graphical and "easy to read" communication skills. Albeit not explicitly identified as "integration experts", they played the core integrative role in the project.

Within these three groups of actors (scientists, practitioners and integration experts), the individuals' roles, the levels of participation and the intensity of their collaboration varied over the course of the project. While we cannot capture the diversity within the three groups, we can differentiate the perceptions of CT across three groups of transdisciplinary partners with a stable group identity: being a scientist (employed at a university located outside of the study region), an integration expert (consulting firm located outside the region), or a practitioner from the region.

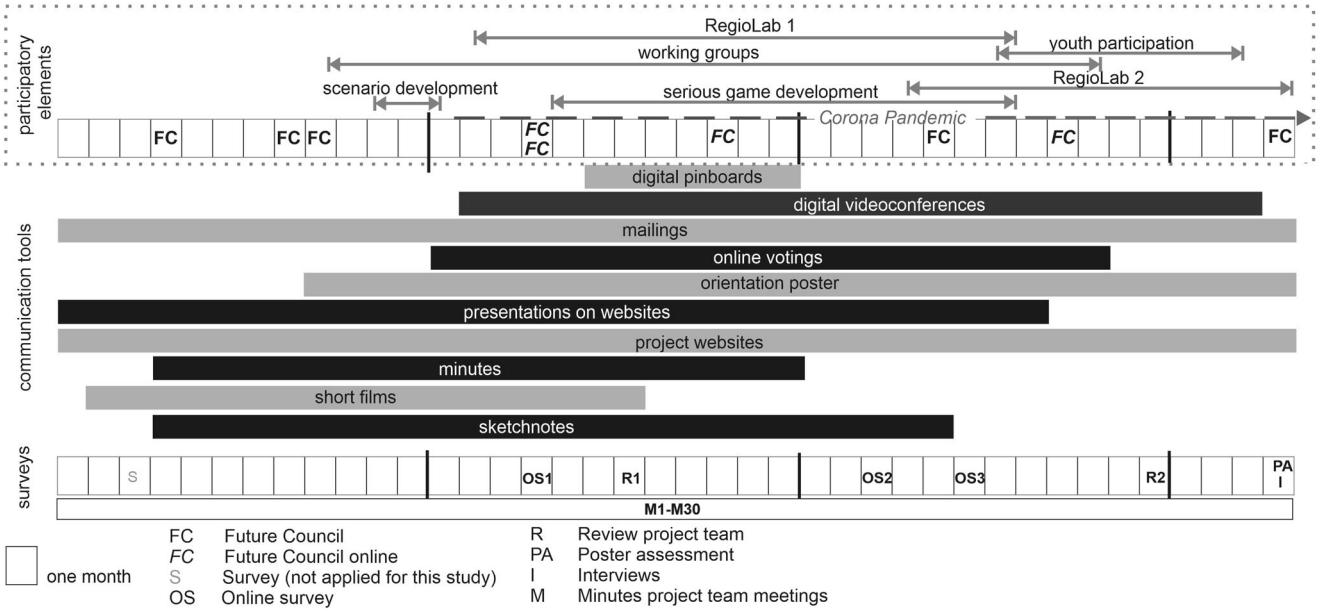

Fig. 3 Overview of the various participatory elements and communication tools applied in the course of the "RLC 2040" project. The top section of the figure shows the timing of the participatory elements and future councils. The middle section shows the different communication tools used to provide support at different times. The lower part of the graph (surveys) shows the elements used for this study (own illustration).

The Future Council involved representatives from local government (e.g., mayors, interest groups, businesses or civil society) and randomly selected people from the region. During the project period (see Fig. 3), nine meetings of the Future Council took place with the intention of integrating practical and scientific knowledge to form an integrated picture of the region, developing a regional vision through a scenario planning process, and identifying action areas where preliminary ideas could be implemented. These events were interspersed with information sessions, presentations, small group meetings, and training opportunities.

We followed Bagnol et al.'s (2016) advice for dynamic communication, which aimed to reveal and unite actors' perspectives, thereby facilitating learning and relationships. Face-to-face and tool-based communication promoted understanding, integration and transparency. The project team was open to new tools and tried to use everyday language to communicate at eye level via different forms (written, visual), tools and channels of communication. The integration experts, in coordination with the project team and the Future Council, were assigned the task of communication planning and implementation, which also included the CT. Although the quality of the individual CT is not the focus of this study, we have incorporated recommendations from the literature on communication in transdisciplinary processes (e.g., eye level communication, common language) in designing the various analogue and digital CT in the project.

The COVID-19 pandemic, with several lockdowns and much uncertainty for social interaction, occurred in the 9th month of the project and required the project team to be flexible in terms of project workflow and communication and to switch to digital CT. This crisis thus provided a window of opportunity to apply and test a variety of digital CT. In the analysis, we focus on CT that complemented the transdisciplinary workshops (see Fig. 3). These CT supported communication among and between the project team and the Future Council as well as the various practitioners, scientists and integration experts involved. The design of the project website consumed most of the costs as it was outsourced to an external service provider. All other CT were created and maintained by the integration experts. Little cost was incurred as free tools or existing digital tools were used.

Communication tools tested in the "RLC 2040" project. Based on the experience of previous regional, trans- and interdisciplinary projects, and considering the needs of the actors involved, the available financial and time resources, and the context-specific conditions in and between the lockdowns, the project team discussed the choice of appropriate CT. This context-specific, flexible, agile and dynamic choice of CT was in line with the literature (see Bagnol et al., 2016; Kushnir, 2021; Nagy et al., 2020; Robasky et al., 2020). To provide a differentiated analysis of the tools, we distinguished between different directions (two-way, one-way), various forms of communication (temporal, semiotic, organisational), levels of participation (information, consultation, knowledge co-production and empowerment) and level of group identity. Tables 1–3 show the digital and analogue tools used in the project and analysed in this paper.

The administrator created and/or maintained the tool and filled it with content. The editor supplemented the tool with content or expanded upon it. The 7th and the two columns on the far right contain an ex-post perception of integration experts regarding costs and time to create and maintain tools.

Data collection and analysis

For this study, we chose a multi-methods approach, including three surveys completed by 69 Future Council members, a poster assessment ($n = 46$), and six interviews with scientists and practitioners.

The three online surveys were conducted to get more detailed insights into practitioners' needs regarding collaboration and CT. The first online survey with the Future Council members took place 16 months after the start of the project (see Fig. 3). It consisted of eight questions, half of which related to digital CT, frequency of use and perceived support for collaboration, or reasons for not using them. Toward the end of the project, we conducted a second online survey (OS2) with 20 partly open and

Table 1 Digital tools (⇔ two-way communication/→ one-way communication; synchronous (syn)/asynchronous (asyn); auditory (auto)/visual (vis)/audiovisual (auvis)/ textual (text); internal (int)/external (ext); information (info)/consultation (con)/knowledge co-production and empowerment (c-pro); integration experts (IE), scientists (S), practitioner (P)).

Communication tool	Direction	Temporal	Semiotic	Organisational	Level of participation	Level of group identity[a]	Description	What was it introduced for?	Administrator	Editor	Costs[a]	Time required[a]
Digital pinboards $n = 5$	⇔	asyn	vis, text, auvis[b]	int	info, con, c-pro	High	• Free online tool • Creation, sharing and discussion of content • Creation of images, text and drawings • Sharing documents and links • Commenting on entries • Display during online meetings and use in presentations • Managed by a moderator from the project team	• To support the work of smaller groups of the Future Council • To develop project ideas and sketches for implementing the vision • To enable participants in each working group to exchange ideas online, share documents and content, post their ideas, and develop project content for discussion • To make progress in the group visible to all group members	IE	S P	Low	Low
Digital video-conferences $n = 31$	⇔	syn	vis, text, auvis	int	info, con, c-pro	High	• Common cloud-based videoconferencing service • Virtual interaction and online meetings • Participation via computer with webcam or smartphone • Hosted by members of the project team • Time-bound • Records of some Future Council meetings available on the project website	• To be able to hold Future Council meetings online (in times of lockdowns) • For short information sessions on the status of the project • For guest lectures • To inform the mayors of the region	IE S P	IE S P	Low	Low
Mailings $n = 46$	⇔	asyn	vis, text	int	info, con	Low	• Installation of a project email list • Attachments such as sketchnotes • Hyperlinks to documents and materials posted on the project website	• For written communication between individual project team members and the Future Council • To send invitations, project information and short reports from meetings • To communicate information beyond the project • To draw attention to surveys, further	IE S		Low	Low

Table 1 (continued)

Communication tool	Direction	Temporal	Semiotic	Organisational	Level of participation	Level of group identity[a]	Description	What was it introduced for?	Administrator	Editor	Costs[a]	Time required[a]
								training offers, project-relevant information, project news, opportunities to participate in RegioLabs or working groups				
Online votings $n = 5$	⇔	asyn	text	int	c-pro	Low	• Anonymous online votings • Sometimes combination with surveys (open and closed questions) • Voting link sent out in mailings and posted on project website • Open for about a month • Presentation of the voting results to the members of the Future Council and publication on the project website	• To vote on the options developed in the Future Council • To gather the views of the Future Council • To get feedback on the vision from young people in the region	IE S		Low	Middle
Project websites $n = 2$	⇔	asyn	vis, text, auvis[b]	ext	info, con	High	• At the beginning of the project, use of the existing website of the regional development association (subpage on the project) • In the middle of the project, creation of a project-specific website with its own URL www.rlc2040.at • Interface to other CT such as digital noticeboards, recorded videoconferences, online voting, presentations, minutes, short films and sketchnotes • Inclusion of image galleries and media coverage • News announcement • Users comments on articles	• To have a central platform where all information was documented and offered in a structured way • To provide continuous information on the project process and progress • To highlight news • To introduce the people involved in the project	IE	IE S P	High	Middle

[a]Ex-post perception of integration experts.
[b]Refers to the films embedded.

partly closed questions, asking Future Council members to reflect critically on past and future collaboration in the Future Council. For both surveys, we emailed the link to the survey to the Future Council members and sent a reminder after 2 weeks. The surveys were anonymous, open for one month each, and comments were allowed.

A third online survey (OS3) was conducted among 25 practitioners who had left the Future Council. Closed questions were asked about their reasons for leaving and the conditions under which they would consider participating in the Future Council again. There was an opportunity to leave comments on each question.

At the last Future Council meeting, 46 representatives from all three actor groups evaluated the CT using a poster assessment. This was an ex-post assessment of their perception of the tools' integration support. The guiding question was: How did CT support integration in the "RLC 2040" project? Based on Jahn's (2008) three dimensions of integration and recent transdisciplinary literature, the following statements were derived:

- Q1: CT gave me an overview of the project and helped me to orientate myself in the project (social-organisational dimension, Jahn, 2008);
- Q2: CT helped to create a common group understanding and promoted my perception of other perspectives (social-organisational dimension, Jahn, 2008);
- Q3: CT helped to bring together scientific and practical knowledge and fostered my learning (cognitive-epistemic dimension, Jahn, 2008);
- Q4: CT presented the project contents appropriately and supported me in the exchange of information (communicative dimension, Jahn, 2008).

Individual poster assessments were anonymous, but participants assigned themselves to one of the three actor groups. Participants rated the CT according to a five-point scale from one (very good) to five (not enough).

Following the poster assessment, we conducted six open interviews (I1–I6) with individual actors (three practitioners and three scientists) to gain deeper insights into the actors' perspectives on the CT used. Respondents explained their poster ratings in detail and explained how they arrived at their ratings. In addition, feedback from the members of the Future Council was considered, which the integration experts received verbally and by e-mail during the project.

The minutes (M1–M30) of 30 project team meetings and two team reviews (R1, R2) added to the wealth of material, enabling an in-depth examination of the 10 CT.

Based on the research question "how do CT support the various dimensions of integration among different actor groups in a transdisciplinary research project?" we shed light on two aspects of CT. We analysed their support for the different dimensions of integration according to Jahn (2008) and how different actor groups (scientists, practitioners and integration experts) involved in a transdisciplinary research project perceive different CT.

The online surveys (OS1–OS3) were analysed using descriptive statistics, with open questions and comments evaluated qualitatively. The results of the online surveys were used to describe CT for practitioners and to analyse the attitudes and wishes regarding the transition to digital tools.

The statements of the poster assessment were assigned to the dimensions of integration (Jahn, 2008), analysed descriptively according to actor groups and different CT (frequencies, weighted arithmetic mean or arithmetic mean, median and range of the assessments) and presented in Figs. 4 and 5. A qualitative content analysis helped to analyse the group-specific perceptions in the interviews (I), the minutes of the team reviews (R) and the minutes of the project team meetings (M). Some quotations are included in the results section to illustrate the findings.

Results

After a general overview of the integration support by different CT, we will present our findings differentiated according to the three dimensions of integration (see Fig. 4), and the three actor groups (see Fig. 5), thus complementing the poster assessments with key results from interviews (I), online surveys (OS), minutes (M) and team reviews (R).

Overall, the actors appreciated the mix of different CT (I1, I2, I5, I6, M1) and all 10 CT used received high support in the poster assessment (Figs. 4 and 5; 1 = very good, 5 = not enough). The orientation poster, sketchnotes, digital videoconferences and websites were perceived as having the highest integration support (Fig. 4). These CT used visual and textual sign systems and facilitated a high level of group identity (Tables 1–3). The orientation poster and sketchnotes supported one-way communication and the lowest form of participation (information) (Tables 2, 3). They primarily provided orientation and an overview on the project as a whole, so that the actors were able to locate individual activities and (partial) goals depicted in words and pictures in the larger project context (I2, I4, M23). The orientation poster was described by one practitioner as a "living document" to "look at what has happened" (I3). Digital videoconferences and project websites supported two-way communication although only digital videoconferences provided the highest form of participation (knowledge co-production and empowerment, Table 1). They were perceived as contributing to learning through good moderation as well as compact and transparent presentations (OS2). In the future, all groups of actors would like to see a mix of face-to-face meetings for creative interaction and digital meetings for information exchange (OS2,3). The project-specific website served as a central information platform (I1–I3, M1, M6, M7, R2), was perceived as a "top product" (R2), and practitioners found "everything they needed there and received the necessary orientation" (I1, I2). Actors used the websites to gather the information they needed, to follow the progress of the project and to receive the latest news. Scientists preferred a specific project website to subpages on existing websites because it contributed more to a good understanding and one could respond to a structure adapted to the project, "even if the transdisciplinary approach could have been presented better" (M6).

Mailings, online votings and minutes are at the bottom of the list of CT rated in the poster assessment (Figs. 4 and 5). Mailings and presentations on websites scored poorly, especially in the group of scientists. As the content of the presentation on the websites came from the scientists, these tools contributed little to (knowledge) gain for this group. Although online votings enabled the highest level of participation, they did not allow for direct exchange and were therefore perceived as comparatively less supportive of integration. While mailings and minutes were used for one-way communication and information, votings allowed an immediate insight into respondents' opinions (I2) and co-decision making. However, all three poorly rated CT conveyed a low level of group identity (Tables 1, 2).

Figure 4 shows the small difference in the weighted arithmetic mean across the three dimensions of integration. When looking at all CT in one dimension (1 = very good, 5 = not enough), support for the communicative dimension (weighted mean = 1.8) ranked first, followed by the cognitive-epistemic dimension (weighted mean = 1.9) and the social-organisational dimension (weighted mean = 2.0).

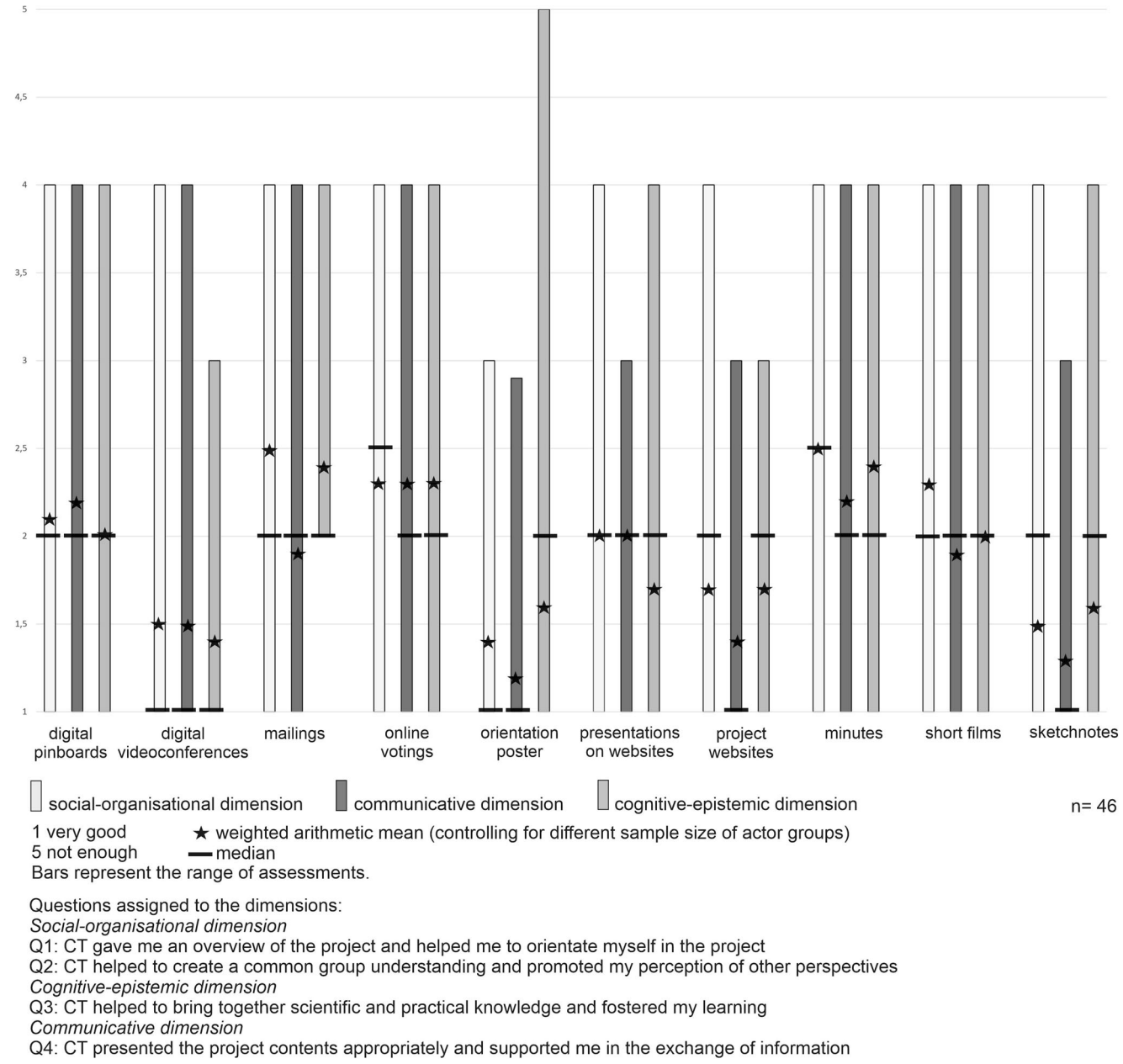

Fig. 4 Communication tools and their support for integration. The figure shows the perceptions of all actors of the 10 communication tools used in terms of their support in each of the three dimensions of integration (communicative, cognitive-epistemic and social-organisational dimensions) (own illustration).

Focusing on the communicative dimension, the poster assessment asked about the support of the CT for information exchange and the appropriate presentation of the content (Q4). Regarding communicative integration, the orientation poster (weighted mean = 1.2) scored best although it was once rated "not enough" by a practitioner, followed by sketchnotes (weighted mean = 1.3), project websites (weighted mean = 1.4) and digital videoconferences (weighted mean = 1.5). According to the interviews, the orientation poster and sketchnotes provided "short and snappy" orientation and key information in words and pictures, conveyed a good chronology of events (I4), "gave something visually" (I6) and invited "one to stop and reflect because it is beautifully designed" (I3). Sketchnotes were "not enough for learning, but great for remembering things" and for orientation (I2). The websites explained or illustrated scientific terms used in the project (M6, M7). Members of the project team argued that for them it was crucial to "translate scientific language into everyday language" (I1, I2), and practitioners acted as "translators" (M1). Although not at the top of the list, short films were seen as a good introduction to a new topic (M15, M17), but were only watched during the presentation in a Future Council and not afterward (I1).

For the cognitive-epistemic dimension, the poster assessment asked whether the CT helped to bring together scientific and practical knowledge to support learning (Q3). Digital videoconferences (weighted mean = 1.4), sketchnotes (weighted mean = 1.6), the orientation poster (weighted mean = 1.6) and project websites (weighted mean = 1.7) received the best ratings. Digital videoconferences scored highest in this dimension and their strength was seen in the transfer of information (R2). These digital meetings "did not create memory images" (R2), though, whereas the project team had vivid memories of the face-to-face

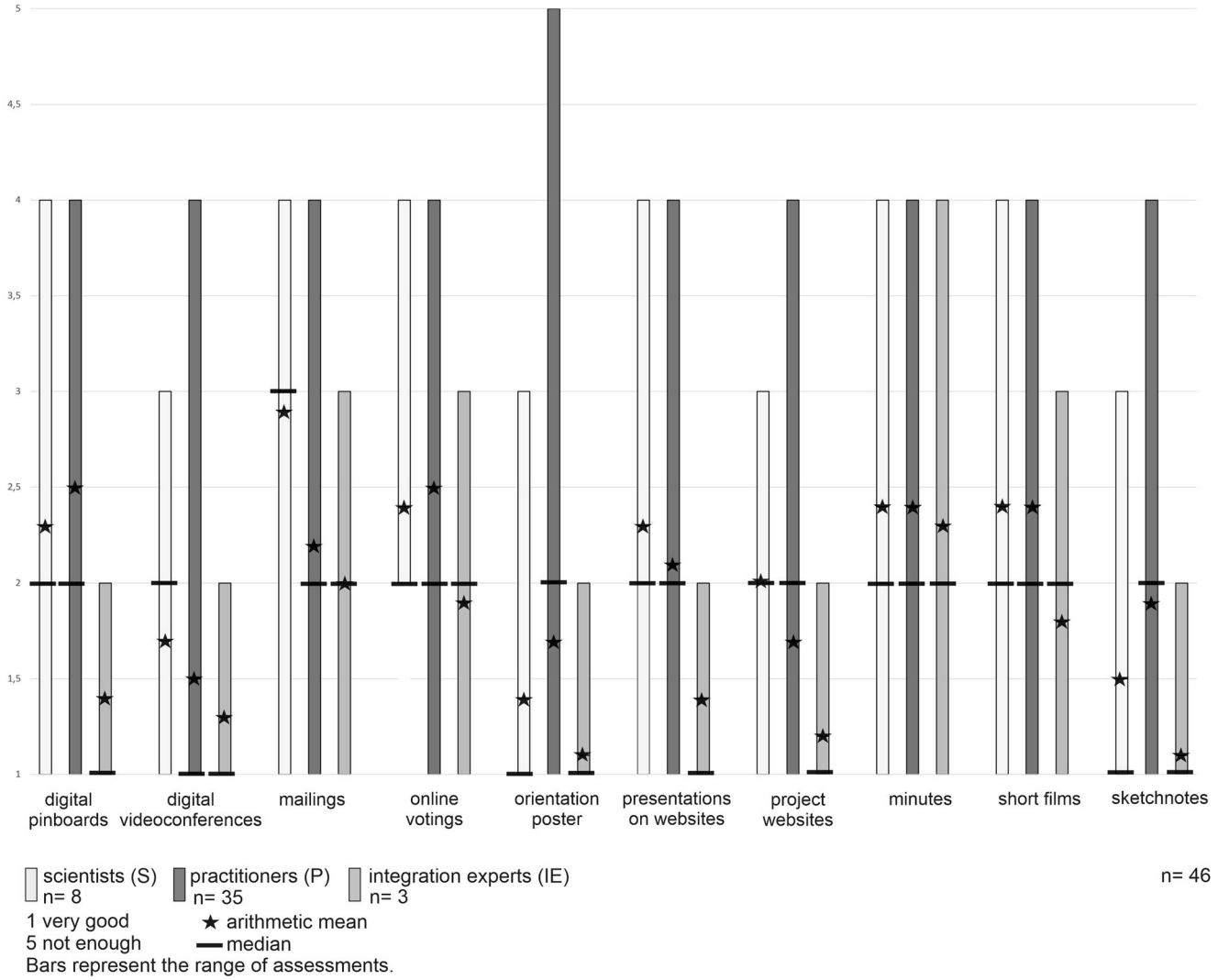

Fig. 5 Communication tools and their support for actor groups. The figure shows the perceptions of each group of actors (scientists, practitioners and integration experts) of the 10 communication tools used in terms of their support in all dimensions of integration considered together (own illustration).

Future Councils and transformative learning was only possible through personal interaction (R2). The orientation poster and sketchnotes "brought science out of its ivory tower" (I6) and presentations on websites provided "figures, data, facts in a condensed form" (I2).

In the poster assessment of the social-organisational dimension, actors rated the support of CT in orientation and overview, in promoting a common group understanding and in perceiving other perspectives (Q1, Q2). Regarding social-organisational integration, the orientation poster scored best (weighted mean = 1.4), followed by sketchnotes (weighted mean = 1.5), digital videoconferences (weighted mean = 1.5) and project websites (weighted mean = 1.7).

The orientation poster gave a good overview of what was happening "in the Future Councils, but also elsewhere in the project" (I2, I4, M23). It was "just cool and something like a corporate identity" (I1) and "brilliant" (I4). In the first Future Council, the actors expressed the wish to have a "central website where we can find everything".

The largest differences between the actor groups were found for the digital pinboards (mean = S 2.3; P 2.5; IE 1.4) and mailings (mean = S 2.9; P 2.2; IE 2.0). For the integration experts, the digital pinboards provided a good overview of the individual project ideas contributed by the practitioners and reduced the preparation time for online meetings with practitioners (M20). Practitioners found the digital pinboards "partly confusing" (I2) but also "good to work with" (I2). They considered the digital pinboards to be the most difficult, mainly as it was a new tool (I2, I3) and it took time to register in advance. The scientists wanted to use the digital pinboards selectively (I6). Although mailings scored low among scientists, they were an important tool for them to inform Future Council members (I4). Practitioners noted that they read emails for pre-event information (invitations), but did not read the summaries after the meetings (I1, I2) because they found everything they needed to know on the websites, which was seen as a necessity: "You can't do it without a website" (I3).

Scientists preferred the orientation poster (mean = 1.4), sketchnotes (mean = 1.5), digital videoconferences (mean = 1.7) and project websites (mean = 2.0). Mailings (mean = 2,9), minutes, short films and online votings (all means = 2.4) scored poorly among scientists. They valued the minutes as a support when there were conflicting memories or misunderstandings (I4), and also noted that they generally did not read the minutes (R2). They commented positively on the films' reference to the region, e.g. people from the region were interviewed or introduced (M15, M17).

Table 2 Tools used both analogue and digital (⇔ two-way communication/→ one-way communication; synchronous (syn)/asynchronous (asyn); auditory (auto)/visual (vis)/audiovisual (auvis) textual (text); internal (int)/external (ext); information (info)/consultation (con)/knowledge co-production and empowerment (c-pro); integration experts (IE), scientists (S), practitioner (P)).

Communication tool	Direction	Temporal	Semiotic	Organisational	Level of participation	Level of group identity[a]	Description	What was it introduced for?	Administrator	Editor	Costs[a]	Time required[a]
Presentation on websites $n = 18$	→	asyn	vis, text	ext[b]	info	Low	• Use of slides at face-to-face and/or online events • Creation of presentations available on the website for independent viewing	• To present project topics and results • To visualise the content of presentations • To make content accessible online in the long term	IE S		Low	Low
Minutes $n = 13$	→	asyn	vis, text	int	info	Low	• Detailed written minutes of face-to-face Future Council meetings, including photos • Printed copies made available at subsequent events • Available on the websites; inclusion of links to the minutes in mailings	• To have written records of Future Council meetings • To have a reference in case of misunderstandings or questions • To justify and understand future decisions • At the beginning more comprehensive, later partially replaced by reports and deliverables on the website	IE	S	Low	Middle
Short films $n = 9$	→	asyn	auvis	int, ext[b]	info, con	High	• Created with low-cost video editing software • Short films of two to four minutes • Presentation at the Future Councils • Available on the website	• For short summaries • To present thematic areas, actors and initiatives from the region • To feature interviews • To make the vision more tangible	IEP		Low	High
Sketchnotes $n = 10$	→	asyn	vis, text	int, ext[b]	info	High	• Drawn notes consisting of text (key points) and visualisations • Presentation of contents (briefly and clearly, but also comprehensibly and illustratively) • A "different way of keeping minutes" • Elaboration after the events • Available on the website and sent out in a mailing • Printed A0-posters for future events	• As a supplement, traditional minutes are reluctant to be read • To facilitate the identification of key outcomes of Future Council meetings • To enable actors to more quickly and easily make associations with specific meetings (when, where, what?)	IE		Middle	High

[a]Ex-post perception of integration experts.
[b]Embedded in the websites.

Table 3 Analogue tools (⇔ two-way communication/→ one-way communication; synchronous (syn)/asynchronous (asyn); auditory (auto)/visual (vis)/audiovisual (auvis)/textual (text); internal (int)/external (ext); information (info)/consultation (con)/knowledge co-production and empowerment (c-pro); integration experts (IE), scientists (S), practitioner (P)).

Communication tool	Direction	Temporal	Semiotic	Organisational	Level of participation	Level of group identity[a]	Description	What was it introduced for?	Administrator	Editor	Costs[a]	Time required[a]
Orientation poster $n = 1$ (see Fig. 2)	→	asyn	vis, text	int	info	High	• Hand-drawn sketchnote (text and visualisations, 5 ×1.2 m) • Illustration of the project process from start to finish • Continuous recording of key events and outcomes to this "living document" • Presentation and display at the face-to-face Future Council meetings • Due to its size, some parts available online (photos)	• To provide a quick overview of the "state of progress" • To give orientation in the complex project and its individual elements • To be used at the beginning of each face-to-face Future Council meeting for common reflection on the previous steps • To be used in a small book at the end of the project as a "give-away" to the Future Council members (photos and excerpts of the poster)	IE		Middle	High

[a]Ex-post perception of integration experts.

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Among practitioners, digital videoconferences scored highest (mean = 1.5), followed by project websites, the orientation poster (both means = 1.7) and sketchnotes (mean = 1.9).

The majority of respondents saw digital media as a very good alternative (52%) and could well imagine shorter, digital meetings to complement face-to-face meetings (63%) (OS1). They valued them in particular for conveying compact information and for their spatial and temporal efficiency. (OS2). It was emphasised as a great alternative "especially for people who would not otherwise have the opportunity to attend such meetings", and they saved "trips and time" (OS2). 18% of those who did not attend the first Digital Future Council cited digital opportunities as the reason ("don't know about the technology", "digital collaboration is not a sensible alternative", "only interested in joint collaboration on site"; OS1). 29% followed at least the events on the project websites (OS1). Practitioners proposed a pre-meeting digital session for concise information exchange before vital face-to-face sessions (OS2) that are central to creative collaboration in transdisciplinary projects.

The integration experts twice gave the highest ratings (mean = 1.1) to the orientation poster and the sketchnotes, followed by the project websites (mean = 1.2) and digital videoconferences (mean = 1.3). The integration experts acted as facilitators. The orientation poster and sketchnotes supported them in this role, both in preparing for and conducting the face-to-face meetings. These CT made it unnecessary to prepare other project overview materials, as they visualised and simplified everything that happened (R2). The integration experts rated all the CTs better, with some clear differences (e.g., pinboards) compared to the other two groups of actors.

In a nutshell, the CT that performed well (orientation poster, sketchnotes, digital videoconferences and websites) all conveyed a high level of group identity and all used visual and textual sign systems. However, they differed in direction, timing or level of participation. Apart from these four CT, short films and digital pinboards also had high degrees of participation, ranking sixth and seventh. The poorly performing CT (mailings, minutes, online votings; with different sign systems, level of participation) all had a low level of group identity (see Tables 1–3).

Discussion

The COVID-19 pandemic provided an opportunity to explore and compare ten analogue and digital CT regarding their support for three different dimensions of integration (Jahn, 2008). Our findings confirmed the supportive role of CT in communication and integration in transdisciplinary research (Bammer, 2013; Boix Mansilla, 2006; Fleming et al., 2021; Godemann, 2008; Godemann and Michelsen, 2008; Härtel et al., 2015; Hasler, 2007; Kushnir, 2021; Lang et al., 2012; Misra and Lotrecchiano, 2018; Pennington, 2011; Pohl et al., 2021; Potterbusch and Lotrecchiano, 2018; Robasky et al., 2020; Wang et al., 2018). We found Jahn's (2008) distinction helpful in looking at integration from a broader perspective and thinking beyond knowledge integration (Pohl et al., 2021). This multidimensional approach made it possible to evaluate supporting elements such as organisational work (Boix Mansilla, 2006), appropriate presentation methods (Robasky et al., 2020) or the management of the knowledge process (Fei, 2011) during the project.

The four tools perceived as most supportive of integration (orientation poster, sketchnotes, digital videoconferences and websites) all conveyed a high level of group identity, while they differed regarding the direction of communication, temporal and semiotic forms, internal or external communication, and level of participation. This confirms that integration in inter- and transdisciplinary projects also depends on emotional factors, including group identity (Boix Mansilla, 2006; Pohl et al., 2021) and actors' sense of involvement (Fleming et al., 2021). The orientation poster and sketchnotes were elaborate, large-format handwritten drawings and feedback from the actors indicated that these tools engaged them emotionally and helped to create an identity. Our results therefore suggest that Jahn's dimension of integration should be complemented by an emotional dimension (Pohl et al., 2021). It would be interesting to see how an emotional dimension would compare with the other dimensions of integration, which received very similar assessments in our analysis.

Regarding the cognitive-epistemic dimension, linking scientific and practical knowledge (Bergmann et al., 2010) and negotiating perspectives (Peukert and Vilsmaier, 2021), digital videoconferences, which came closest to face-to-face meetings, were perceived as the most supportive across all actor groups. Our findings confirmed digital tools´ crucial role for transparency and information flow (Fei, 2011; Härtel et al., 2015), and integration (Fei, 2011; Potterbusch and Lotrecchiano, 2018). Beyond clear and coherent knowledge presentation (Bergmann et al., 2010; Defila et al., 2006; Jahn, 2008), they support communicative knowledge transfer encompassing accessible knowledge resources (Anders, 2013), connectable language (Krainer et al., 2014), and visual tools (Godemann, 2008; Lang et al., 2012). Fewer mobile actors (e.g., caring parents) appreciated the benefits of videoconferences, such as saving time or travelling. They offered the opportunity to participate or be informed, regardless of when or where they wanted to get involved. At the same time, they represented access barriers for other actors (Leitner, 2018). Although useful for "quick information" between face-to-face meetings, digital videoconferences could only partially satisfy actors' needs for social interaction and creative working methods. This leads to the conclusion that knowledge co-production requires face-to-face participatory, creative methods and exchanges, even if information sharing can be facilitated by platforms and comprehensible communication (Godemann, 2008; Härtel et al., 2015; Siew et al., 2016).

In line with Pohl et al. (2021), we saw integration as an open-ended learning process between heterogeneous actors and their different perspectives. We used a variety of CT to address heterogeneous actors and their perspectives with different communication formats and intensities. In our project, the actors evaluated the mix of CT, all of which received good to very good assessments. We conclude that a "both/and" rather than an "either/or" approach to CT selection is appropriate for heterogeneous groups, which is in line with more information sharing as a better way to achieve integration (Fleming et al., 2021). Various CT catered for different learners due to varied content depth. They supported the exchange and enabled integration through result formats that prepared the different types of knowledge in an appropriate way for delivery and modification (Nagy et al., 2020). CT that were already produced in the course of the project (e.g., presentations, short films, minutes, online votes) were made available to the practitioners via the project websites (without additional effort for the project team and for flexible use by practitioners).

The orientation poster and sketchnotes—although analogue, with one-way communication and the lowest of participation—received the highest ratings in the communicative and social-organisational dimensions and the second and third ratings in the cognitive-epistemic dimension. They facilitated quick orientation, displayed achievements, evoked pleasure (Boix Mansilla, 2006), but required specific graphical skills and the ability to present scientific knowledge in a coherent way. The orientation poster and sketchnotes were useful for event preparation, research content design (Lang et al., 2012) and process management (Aenis, 2010; Fry et al., 2008; Lang et al., 2012; Lieven and Maasen, 2007).

The accessible information on the project websites facilitated knowledge exchange, enhanced transparency and relationships among actors, and provided concise insights that supported

navigation within our complex project (Godemann, 2008; Godemann and Michelsen, 2008; Misra and Lotrecchiano, 2018; Pennington, 2011; Potterbusch and Lotrecchiano, 2018; Robasky et al., 2020). The project website met practitioners' need for a central platform, not limited by time or place (Robasky et al., 2020). Having a website and up-to-date information about the project online, including a logo and photos, was seen as essential ("you can't do it without a website") as it increased presence, visibility and identity.

The group of integration experts—possibly because they had pre-selected and implemented the tools—rated all the CT better than the other actor groups. The biggest differences between the groups were found for digital pinboards, mailings and presentations on websites. Digital pinboards were rated the lowest by the practitioner, even though this tool allowed two-way communication and the highest form of integration, as well as a high level of group identity. They preferred to use tools that they knew and were already used to. However, when distinguishing between the three different actor groups, we have to acknowledge that we could not capture the diversity within each group and that individual CT quality was not addressed.

Due to COVID-19 lockdowns, a dynamic communication adaptation was particularly important due to the constantly changing conditions (Bagnol et al., 2016; Kalmár and Stenfert, 2020; Krainer et al., 2014; Kushnir, 2021; Pohl et al., 2008). Diversity of team experiences allowed for context-specific strategies (Bagnol et al., 2016; Kushnir, 2021; Nagy et al., 2020; Robasky et al., 2020). Regular consultation through surveys and informal exchanges, as recommended by Robasky et al. (2020), ensured context-specific CT decisions. Creating and updating CT required effort from the project team (Tress et al., 2007), but proved valuable for providing updated information to actors in a timely and easily accessible manner (Bammer, 2013; Mitchell et al., 2015; Schmohl and Philipp, 2021). Digital tools supported project progress and outcomes (Potterbusch and Lotrecchiano, 2018) and facilitated the preparation of meetings and reporting. The use of (extra) digital CT was limited by financial and time resources and the skills available in the participating groups (Leitner, 2018).

Limitations of the research design include the comparative assessment of the ten CT, which was based mainly on an ex-post poster assessment and interviews with participants of our final Future Council. Although minutes and surveys at different stages of the project complemented the ex-post assessment, the latter might have created a bias by self-selection (the perceptions of the last meeting's participants got more attention) and a recall bias (later interactions with CT might have been recalled more clearly than those at earlier stages. Post-factum actor perceptions might favour the recall of long-term tools in the 3.5-year project. For the poster assessment, we exploratively operationalised the complex dimensions of integration with four short questions (one for each of the communicative and cognitive-epistemic dimensions and two questions for the social-organisational dimension). Furthermore, the validity of the results of this article is limited by the self-selection of participants. Those who dropped out of the Future Council—although included via an online survey on the use of digital tools—obviously did not participate in the final Future Council meeting with the comparative poster assessment of the CT. For future comparative analyses at different project stages, there is definitely a need to better operationalise the dimensions of integration. Nevertheless, we argue that our explorative multi-method approach, which includes project team reviews, project team meeting minutes and the three surveys at different project stages with participants and drop-outs, has helped to mitigate some of the limitations of the ex-post poster assessment. Further, it has allowed us to gain initial insights into how different actor groups perceived the integration support provided by ten different CT.

Future research will have to investigate the feasibility of developing a scale to capture the various integration dimensions more accurately. This should include a fourth, emotional dimension of integration. Such a scale could help to improve the measurability and comparability of integration in different contexts. Further studies could focus on how CT can support the use of individual methods for knowledge integration (e.g., participatory development of scenarios or serious games). It could also be examined how CT can facilitate inclusive communication and access to groups of actors that are often underrepresented in transdisciplinary projects.

Conclusions

CT enable and structure interactions in transdisciplinary projects. They support knowledge exchange, feedback and a shared learning and decision-making process. They help to document results in a way that is accessible to diverse participants. In a nutshell, they support integration. Integration as a multidimensional concept is highly valued in transdisciplinary research but has not yet been operationalised for empirical research. Our explorative multi-methods analysis compared 10 CT along the socio-organisational, cognitive-epistemic and communicative dimensions of analysis.

The four CT the actors perceived as most supportive of all three dimensions of integration (orientation poster, sketchnotes, digital videoconferences and websites) used visual and textual sign systems and facilitated a strong group identity. We conclude that it was helpful to consider integration beyond the cognitive dimension. Future research should include and operationalise an emotional dimension of integration for comparative analysis at different stages of transdisciplinary projects.

For practical communication in transdisciplinary research projects, we propose a central information platform (e.g., a project website) where actors can find a variety of information independent of time and place, and a tool that gives actors a quick and comprehensible overview of the whole project and its key components in words and images (e.g., orientation posters, sketchnotes). The design of the tools should ensure that actors feel emotionally involved and that practitioners, in particular, are provided with technical tools they are familiar with. When setting up transdisciplinary project teams, it can be beneficial to include integration experts who can contribute not only time resources but also have communication, visualisation and technical skills. If these integration experts are able to flexibly create and edit content themselves, this eliminates the need for additional interfaces with third-party external communicators and supports a dynamic communication strategy that can be flexibly adapted to the changing communication needs of a heterogeneous group.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions

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Competing interests

The authors declare no competing interests.

Ethical approval

The research was conducted in line with the ethical requirements of the authors' university.

Informed consent

Informed consent was obtained in written form from all participants in the research. The individual participants in studies have been informed about the use of the data (e.g. scientific publication) and their right to decide what happens to the (identifiable) personal data gathered, to what they have said during a study or an interview, as well as to any photograph that was taken. Furthermore, all participants have been informed about which type of personal information will be taken into account in the research in an anonymous form, e.g. age, gender, level of school education.

Additional information

Correspondence and requests for materials should be addressed to Verena Radinger-Peer.