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An Impossible Turn? The Dialogical/Participatory Potential of Science Communication Provided by Science Centers in Light of Niklas Luhmann's Systems Theory

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Abstract

One important dimension of the debate surrounding science communication is the tension between the implementation of the deficit model and the repeated calls for the adoption of dialogical and participatory models. This article aims to show this friction empirically and interpret it theoretically. The text uses the operation of science centers as a form of science communication. Niklas Luhmann's systems theory serves as a tool to capture the broad structural difficulty in implementing participatory demands in science communication. This paper is based on research conducted in Polish science centers. It demonstrates that even in the organizationally favourable and relatively inclusive conditions offered by these centers, the environment as a whole cannot regulate the activities of the science system. It lacks knowledge of the essential social determinants of research activity and the areas of unfinished science. Conversely, the detailed findings of science are challenging to integrate such that they become comprehensively readable by the community without becoming a scientific black box. Luhmann's theory elucidates this fundamental difficulty in building the science-society relationship. From this perspective, a consistent and broad turn towards the dialogical and participatory model appears impossible.

Keywords: science communication, Niklas Luhmann, systems theory, science center, participatory turn

1. Introduction

Generally, science communication aims to make scientific activity as accessible as possible to non-scientists. This potentially increases accountability and trust in science, ultimately fostering social cohesion concerning scientifically determined facts (Weingart & Joubert, 2019). Maja Horst, Sarah Davies, and Alan Irwin define science communication as "organized, explicit, and intended actions that aim to communicate scientific knowledge, methodology, processes, or practices in settings where non-scientists are a recognized part of the audiences" (2017, p. 883). In recent decades, a considerable part of the work in science and technology studies (STS) has focused on analysing different forms of science communication vis-a-vis the deficit model and the dialogical-participatory models (Wynne, 2006; Trench, 2008; Horst, 2012; Suldovsky, 2016; Horst et al., 2017).

Using Bucchi's (2008, p. 69), classification of the purpose of science communication, the dialogical/participatory approaches involve discussing the implications of scientific research and shaping research directions in a broad social context. In this article, we assume that, given the various concepts and divisions in lines of science communication, the contrast between deficit and dialogical/participatory approaches is the most essential. A similar stance is taken by Horst, Davies, and Irwin (2017, p. 883). Generally, we can describe dialogical/participatory approaches as based on mutual interaction between science and society. In contrast, the primary purpose of science communication under the deficit model is to transfer knowledge unidirectionally (Gross, 1994, pp. 5-6).

According to the findings of science communication theorists, it is possible to conduct forms of science communication that allow the direction of scientific research to be guided by signals from the broader social world, aligning with the idea of public participation in science (Rowe & Frewer, 2004). Dialogical-participatory approaches, which involve non-scientists in the democratization of science, are considered valuable for maintaining social integrity and avoiding conflict by providing opportunities to include the perspectives of different stakeholder groups (Kappel & Holmen, 2019; Metcalfe, 2022). Consequently, participatory forms are considered more effective and beneficial for maintaining trust and transparency in science and government (Stilgoe et al., 2014). Within the broad landscape of science communication (Davies & Horst, 2016), we consider science centers to be distinctive because they can potentially pursue both models, which are described as extremes on a continuum in science communication: deficit and participatory (Bucchi 2008, p. 69). In certain activities, such as temporary exhibitions or meetings with scientists, large science centers are sometimes viewed as institutions that support and stimulate the participatory approach and dialogue with decision-makers. Given their specialization in science communication and the wide range of possible operational forms—from workshops, lectures, and demonstrations to arranging installations with artistic expression (Yaneva et al., 2009)—we posit that these facilities

can serve as a test case for science communication generally. In doing so, we acknowledge the limitations of such an approach, particularly concerning the characteristics of the society in which they operate.

In this article, we rely on the example of Polish science centers, which have existed relatively shortly, since around 2007. Therefore, we assert that they were established after the participatory turn in science communication in the 1990s (Hagendijk & Irwin, 2006). Emerging science centers, such as Polish ones, can benefit from decades of experience of similar institutions that have developed previously in other countries. They can present an improved version of exhibitions and activities after observing the numerous transformations of other entities (Perdretti & Iannini, 2020). Moreover, the case of Poland may illustrate the general readiness to implement dialogical and participatory models in science communication. Poland, as a semi-peripheral country,[1] is not considered a direct consumer of innovation-related benefits. Assuming that the rhetoric of the knowledge economy provides an ideological context for disseminating the deficit model (Bucchi, 2008, p. 69; Trench, 2008, pp. 127-128), we can consider Poland as a country with good conditions for developing dialogue and participation in science communication.

Using Luhmann's theory, we aim to explore the extent to which science centers create a space for building relationships between science and the broader community. Thus, we understand "science communication" as an inter-system relationship. This article seeks to answer the following questions from Luhmann's theoretical perspective:

To what extent do the activities of science centers provide a basis for the realization of communicative selections for the science system?

How much can science benefit or develop from the science communication realized by these facilities?

On the other hand, do science centers contribute to the visibility and readability of the rules governing the operation of the science system?

According to Luhmann's theory, system codes are binary generalizations specific to each system: "Each binary code claims universal validity, but only for its own perspective. (...) Above all, this means that no functional system can enter in place of any other" (Luhmann, 1989, p. 109). We assume that the operation of a system can be sensitive to signals from the environment only if they correspond to the system's operational codes. What remains to be recognized,

[1] Using Immanuel Wallerstein's terminology relating to the political and economic situation, some researchers describe Poland as a peripheral (Lewandowski, 2021) or semi-peripheral (Bielska & Wróblewski, 2017) country.

therefore, is whether institutions of a specific type (like science centers) can ensure the relevance of signals from the environment to science and from science to the environment.

We aim to ascertain the extent to which the chosen form of science communication can increase the receptivity of the system in its relations with the environment. In other words, we can ask whether science centers can contribute to the system's autopoietic sustainability and whether they clarify the code of the science system's operation to the environment. This was accomplished through two stages of empirical research: first, a document study and observation identified the most important operational areas of the science centers. In the second stage, we explored the opinions of management and external designers regarding the dialogical/participatory potential of interactive exhibitions, which emerged as the most distinctive activity.

2. Science centers in science communication research

The need to complement the deficit model with dialogue and participatory approaches has been described in STS theory (Wynne, 1992; Einsiedel, 2008). The UK House of Lords Select Committee on Science (2000) described the deficit model as a "rather backward-looking vision." Moreover, this report directly points to science centers as institutions capable of implementing a participatory approach.

Science centers and science museums are generally open to a broad audience and can attract people from diverse demographics (in terms of age, education, and occupation). However, early analyses of science centers and museums identified difficulties arising from operating primarily based on inflexible, expensive exhibitions (Bradburne, 1998, p. 238), with insufficient attention paid to the social aspects of science development, including political and ethical considerations (Pedretti, 2002, p. 3). Rennie and Williams (2006) highlight the significance of this in shaping science's as "infallible," a notion also discussed by Ana Delicado in the Portuguese context (2009, p. 760; 2014, p. 21). Researchers aver that, despite considerable effort, addressing exhibitions simultaneously to both children and adults is challenging (Hine & Medvecky, 2015).

Nevertheless, quantitative research at the Science Museum in London (Bandelli & Konijn, 2015) shows that it is not prior interest that determines laypeople's participation in discussions about science, but rather the conditions that facilities like science centers provide for visitors. Literature from the last decade has documented successive attempts to introduce changes in this regard to the exhibition spaces in science centers and museums. One characteristic that distinguishes science centers from other cultural institutions is their exhibitions, which consist of interactive objects presenting selected areas of science and

technology. The idea is that visitors can learn about physical and natural phenomena through observation and perception via their own senses (Bradburne, 1998, p. 240) through a "first-hand experience" (Şentürk & Özdemir, 2014, p. 3). Fiona Cameron and Ann Deslandes (2011) address the role of museums and science centers as facilitators of public discourse on climate change. Other researchers observe the functioning of glass laboratories in natural history museums positioned "just a window away from visitors" (Wylie, 2019). Morgan Meyer (2011) describes a laboratory set up in the Deutsches Museum to allow people to watch scientists at work and even discuss research ethics. Similar solutions can be found, for example, at the Exploratorium in San Francisco or the Natural History Museum in London. Meyer notes that such a place is "more about science in the making, rather than science already done" (Meyer, 2011, p. 264). Hence, the change is about trying to complement the image of science by presenting it as an ongoing process (Hine & Medvecky, 2015; Merzagora, 2017; Rössig & Jahn, 2019).

Although based on the idea of dialogue and participation, the above solutions still exhibit characteristics of a deficit model of communication. As Wylie (2019, pp. 6–7) points out, "Fishbowl lab workers (...) conduct legitimate, authentic contributions to knowledge construction. But this work is intended for public witnessing, such as by presenting workers as skillful and professional." Pedretti and Iannini (2020) show that controversies related to scientific research can be present in science center exhibitions. However, these are still only a few examples and do not address the issue of science creation and functioning per se.

3. Theoretical framework

In this article, we follow the assumptions of Niklas Luhmann's social systems theory to analyse the relationship between science and the social environment of non-specialists. Luhmann developed a comprehensive social systems theory emphasizing the complexity and autonomy of social systems. He believed that society consists of various systems (e.g., legal, economic, political, and science) that operate independently but in relation to one another. One of Luhmann's key concepts is autopoiesis, which refers to the self-reproduction and self-maintenance of systems. From this viewpoint, each system has its own unique perspective and operates based on internal logic.

Communication plays a vital role in Luhmann's theory. However, this communication[2] is understood in a specific way, primarily as a self-referential process for the system (Luhmann, 1995, p. 143). In operating within the science system, research procedures and dominant interpretations become established on the basis of the inherent true/false code, which serves as the basis for the self-re-

[2] Not „science communication."

production of the science system in Luhmann's sense. In relation to the environment, science transfers the possible effects of laboratories and research teams to the practice of everyday life for non-science systems that indirectly consume its products. The core sense of a specific system's operation relates to the environment and is stimulated by it, but is based on rules specific to that system (Luhmann, 1992). This means that the persistence of the system occurs on its own terms and is present in the environment. At the same time, this does not imply that the perspective of any system is superior to another. Luhmann emphasizes the increasing complexity and differentiation of modern societies. As societies evolve, various systems, such as science, specialize and become more differentiated, leading to greater complexity and interdependence.

We assume that each social system, including science, operates in a closed manner based on its own rules, in an environment specific to itself (Luhmann, 1995, p. 9). This closed nature of the system means that the environment can elicit the system's reactions only under conditions that correspond to the operational codes of the system (Luhmann, 1995, pp. 142-143). The relationship between the science system and the environment, therefore, consists of building a relationship whereby the actions of other systems can take forms that are readable and meaningful for science. Technically, such a function can be performed by various tools of science communication, including science centers, which can provide a closer look at the principles of research work.

The actions of particular systems can trigger reactions from other systems; for example, changes in available scientific knowledge may prompt alterations in the education or legal system. Similarly, actions in the economy or legal system can evoke responses from the science system. Thus, even the very choice of a research problem or the assignment of priorities to specific scientific issues can be a response to signals from the environment, indirectly affecting the organization of scientific research.

Let us examine the idea of dialogue and participation through the lens of Luhmann's categories of the environment and the science system. On the one hand, participation can strengthen the autopoiesis of science by constantly revising its findings. Many studies that provide insights into the current science-society relationship allow us to argue that democratizing science can be beneficial to science itself as an approach to understanding reality and practically implementing scientific achievements. On the other hand, increased public attention to the principles of scientific discourse could help strengthen public debate or transcend ideological boundaries in the conduct of experiments. What is of interest here is the extent to which organized science communication can bring the science system and the environment closer, contributing to enhanced mutual readability.

A vital part of research in science communication has been conducted from the perspective of science and technology studies. This eclectic approach incorporates various types of theories (e.g. actor-network theory and grounded theory). Nevertheless, the primary advantage of the approaches present in this framework is their orientation toward in-depth, ethnographic description (Metcalfe, 2022). For example, Bonney et al. (2016) describe the special efforts required to make citizen science a tool for better understanding and participation in science. Aleksandra Kołtun (2023) describes the organizational constraints for conducting science communication that engages the public, using science festivals as an example. We propose that the issue of science communication can be approached by complementing anthropologically oriented findings with a fundamentally theoretical perspective. Niklas Luhmann's systems theory (1995; 2012; 2013) enables us to present the fundamental limitations in the activities of science centers concerning the implementation of the dialogical/participatory model. This theoretical approach allows us to explain these limitations rather than merely describing their external manifestations. Moreover, through Luhmann's approach, we can highlight the potential universality of these limitations, which may also be relevant in other forms of science communication, such as citizen science projects or science festivals.

4. Study description and data collection

This paper is based on qualitative research conducted in Poland primarily between 2018 and 2020. We assume that local science centers have been operating since 2007—when the Experyment Science Center in Gdynia opened to the public[3]. Subsequently, the opening of the Copernicus Science Center in Warsaw in 2010 (currently one of the largest science centers in Europe) triggered the creation of similar facilities in other major Polish cities.

Polish science centers operate according to a framework like that of science centers and science museums worldwide, with an overall comparable exhibition style. Seven Polish science centers are associated with Ecsite—the European Network of Science Centers and Museums, which facilitates the exchange of ideas and information among European science centers. The Copernicus Science Center in Warsaw belongs to ASTC—the Association of Science and Technology Centers and EUSEA—the European Science Engagement Association.

[3] Interactive exhibitions have also previously operated in planetariums, city museums, and university museums (Kluza, 2014). However, the Experyment Science Center in Gdynia is the first Polish facility where this type of exhibition constitutes the basis of functioning and is the center of other forms of activity.

Internally, science centers are associated with the Polish network Społeczeństwo i Nauka (eng. Society and Science Association). The transfer of ideas, visual concepts, and technical solutions for exhibitions is also facilitated through the engagement of internationally active exhibition designers.

The data used for this research were collected through document analysis, observations, and interviews. Document analysis is based on promotional and press materials, annual reports, statutes, and cost estimates for new exhibitions. Almost all these materials were publicly available and are treated as basic information for the subsequent steps in the study (observations and interviews). Information about visitor numbers was obtained through e-mail. Structured observations of the exhibitions were conducted in four institutions with high attendance, located in Warsaw, Łódź, Gdynia, and Toruń. Observations were conducted with full participation, documented through notes and photographs, besides 12 semi-structured interviews among three groups of respondents, including directors (five interviews numbered 01 to 05) and managers (four interviews numbered 01 to 04). These respondents represent seven science centers, four of which were also studied through observation. Three interviews were conducted with external exhibition developers (numbered 01 to 03). Respondents were recruited through purposive selection. All interviews were recorded with the interviewees' consent and transcribed. Notably, there are only a dozen or so prominent science centers in Poland, as well as very few individuals who can provide comprehensive answers to broad questions about these institutions. Accordingly, transcriptions required particular care to ensure the anonymity of the respondents, who represent a small circle of recognized institutions. Due to the small scale of the study, interviews were coded in two stages: first, through pre-coding categorization (by listening to audio files) and second, during transcription using MaxQda software.

Our interviews focus on the interactive exhibitions of science centers, primarily because the analysis of the science centers' activities indicates that interactive exhibitions are their best-recognized form of activity. Data on ticket sales from the four major Polish science centers for 2018 enable us to estimate that visiting an exhibition is the goal of around 81% of visits. Semi-structured interviews were conducted using a preliminary scenario divided into five sections, as outlined in Table 1.

To verify the possible extent of achieving the goals of dialogue and participation through these facilities, we sought to determine their place in the system structure. In the interviews, we posed questions about self-characteristics, tasks, mission relations with other institutions, and long-term plans. Through these parts of the interview, we could ascertain their place in the system structure and the main forms of operation (for example, whether there is a way to provide input to science). Another section was dedicated to the exhibition in terms of presenting research practice and controversial issues. In our view, this enables a description of the kind of cross-system science-environment relations

possible, given the organizational potential of science centers as a form of science communication. None of the questions directly referred to the subjective opinion of what kind of science communication model could be pursued by science centers.

Table 1. Topics of the interview

Section	Interview Topic	Related Research Problem	Questions in Luhmann's Categories
1	General characteristics of science centers, declared mission	Orientation towards a dialogue/participatory model in terms of declarations and self-characteristics/ descriptions of main forms of operation	To what extent do science center activities provide a basis for the realization of communicative selections for the science system?
2	Characteristics of a particular facility, manner of operation		
3	Relation of science centers to important partners (e.g. schools, universities, local authorities, and sponsors)		
4	The potential to present the researcher's working space and controversy in science to stimulate debate about current research directions	Potential to present research practice and actual controversial issues (undone science)	Do science centers contribute to the visibility and readability of the rules governing the operation of the science system?
5	Evaluation of contemporary activities and aims for the future	Orientation towards a dialogue/participatory model in terms of declarations/self-characteristics	To what extent do science center activities provide a basis for the realization of communicative selections for the science system?

Source: Own study

5. Results of qualitative research

5.1. Exhibition as a main form of operation

By 2020, more than a dozen places, usually referred to as "science centers," had been established in Poland. The Warsaw Copernicus Science Center has the highest annual number of visitors (over one million each year before the COVID-19 pandemic and over 1,300,000 people in 2023, setting an attendance record. Based on data collected directly from facilities operating in major cities, there are currently at least five year-round establishments, each visited by at least 150,000 people annually (data for 2018). The others attract thousands of

visitors each year. Besides the large science centers, there are several facilities in smaller towns. Poland's science centers usually function as municipal cultural institutions, partly funded by public budgets—regional, national, or international, such as European Union programmes—and partly through commercial activity. In Table 2, we present basic information about Poland's largest science centers.

Table 2. Largest Science Centers in Poland (Annual Number of Visitors Exceeding 150,000 According to 2018 Data)

	Year of Opening to the Public	City	Name	Formal Status	Estimated Annual Number of visitors in thousands (Based on Data for 2018)
1	2007	Gdynia	Experyment Science Center	Municipal cultural institution	213
2	2008	Gdańsk	Hevelianum	Municipal cultural institution	222
3	2010	Warsaw	Copernicus Science Center	Municipal and governmental cultural institution	1,144
4	2013	Toruń	The Mill of Knowledge Modernity Center	Municipal cultural institution	158
5	2018	Łódź	EC1 Center of Science and Technology	Municipal cultural institution	301

The exhibition can be considered the primary form of operation for such institutions, serving as a recognizable "magnet" for visitors. One respondent indicates, "In our strategic plan, the priority is the exhibition (…). The physical experience. This is the best thing we do" (Director_03). The exhibition is also an easily measurable indicator of popularity, compared to other cultural facilities. The estimated pre-opening sales revenue for one of the science centers assumes that 89% will be generated by exhibition ticket sales, constituting almost half of all business revenues (along with space leasing and sponsorship, excluding public subvention).

The exhibition often comprises installations that enable the sensory experience of phenomena related to various fields of knowledge. The gyroscope is a popular element, which can be experienced on one's own body when held on a spinning chair. An exhibition object can be touched, used, and tested. On the one hand, this may emphasize the visitor's subjectivity. On the other, it enables the demonstration of science as a set of recurrent and objective principles that can be learned independently and precisely as an expression of the application of a systemic perspective based on the categories of true and false (Luhmann, 1989, p. 77).

Such exhibits, which encourage testing and interaction by large groups of visitors, must be simple to use, physically durable, factually correct, and visually appealing. Preparing an exhibition is both time-consuming and costly. Information about the costs of arranging exhibitions in newly created science centers suggests that the cost of preparing one square metre of an interactive exhibition amounts to approximately €1,500–2,500 (the analysed budgets were developed between 2007 and 2019). For example, one of the newly emerging science centers predicts the total investment costs for equipment at approximately €5 million (including the purchase of software, furniture, and workshop equipment). Of this, approximately €3 million is earmarked for the permanent exhibits.

The observations conducted indicate that the investigated science centers present selected issues from various fields of science with a strong orientation towards STEM. The exhibition space is usually organized around distinctive themes, but the boundaries between them are blurred. For example, the permanent exhibition of the Experyment Science Center in Gdynia consists of five smaller sub-exhibitions located in one open space: “Operation Human” (concerning biological systems in the body), “Tree of Life” (concerning biology and ecology), “Invisible Forces” (concerning physics), “Towards Health” (concerning health issues), and “Hydroworld” (concerning water in general). Similarly, “The Experimental Zone” opened in 2018 is the main, highly diverse exhibit of the Copernicus Science Center in Warsaw.

Science centers, as facilities targeted at schools and families, can potentially attract people from diverse demographics (in terms of age, education, and occupation). Nevertheless, exclusion in science communication remains a matter of ongoing debate (Dawson, 2014). Observations indicate no need for special knowledge or behaviour among visitors (people can freely touch equipment without prior preparation, be loud, and converse with one another). Spaces are designed to accommodate elderly visitors and small children (equipped with elevators and areas for rest and feeding babies). However, our respondents claim that attracting teenagers is particularly challenging, a common problem for science centers internationally, as it frequently recurs on the agendas of Ecsite conferences.

Simultaneously, wide openness entails limited flexibility regarding content presentation. Thus, the exhibits tend to focus on classical scientific issues and research methods (not currently controversial) or describe the potential of current research works in terms of positive changes. For example, the exhibition "Ideas" located in the Mill of Knowledge (Toruń) presents human inventiveness and expresses an affirmative attitude towards science and technological progress. In the description of the "Operation" exhibit, we read: "Robotic surgery could save many patients in the future, especially in countries suffering from a hortage of skilled personnel." "The Future is Today" exhibition at Warsaw's Copernicus Science Center, fully opened to the public in 2023, highlights the broad opportunities presented by the development of artificial intelligence, as well as some risks associated with, for example, cybersecurity. At the same time, the exhibition is complemented by expert statements regarding measures taken by public authorities to control the threats[4].

5.2. Self-Orientation of science centers in management and exhibition developers' opinions

Mostly, science centers do not conduct their own research but rather organize a space to discuss science and selected research methods. They also facilitate the testing of various confirmed principles, particularly by allowing visitors to recreate a pre-arranged experiment leading to specific cognitive conclusions. In this sense, as we pointed out, science center-type institutions present areas of social reality that can be defined by a true/false code in Luhmann's sense.

As institutions in an organizational sense, science centers operate within other Luhmannian systems, such as education and local politics (Baraldi et al., 2021). As cultural institutions (even if not entirely publicly funded), science centers are involved in enforcing public policy aimed at building a knowledge-based society. The head of one of the Polish science centers said in a press statement on the day of its launch in 2020, "[...] I hope that the youngest explorers will also be inspired to such an extent that in the future they will bind their educational path with directions that are extremely necessary for the development of an innovative and thus competitive regional economy."[5] The operation of the policy system is also evident in the activities of the science centers, where high attendance rates are crucial from the perspective of evaluating the usefulness of the largely public-funded facilities. Local policy interests are also relevant when considering the revitalizing role of science centers in urban spaces. Notably, in knowledge-based economies, science centers can act as tools for anticipated social change (Afeltowicz et al., 2020) and for example, assist in creating human resources for an innovation-based economy. In such circumstances, the

[4] https://www.kopernik.org.pl/en/kampanie-edukacyjno-informacyjne/program-przyszlosc-jest-dzis

one-way educational deficit model could be the preferred choice of local authorities, who play a key role in planning science communication facilities. Dialogical and participatory communication, which assumes deliberation on the safety, usability, and efficiency of new technologies, may prolong the innovation implementation process.

In this article, however, we primarily focus on relevance to the science system. The interviewed leaders and managers recognized that the role of science centers is to connect the academic world with communities not directly involved in scientific research[6]:

> [...]a great social role, [...] demonstrating how science surrounds us, how it affects us, the transfer of that science (Director_01).
>
> It [the role of science centers] is usually defined by such a term [...] participation in science. It's a series of levels that start with science education [...] one that allows you to problematize issues, allows you to better understand their social implications, their context, and to engage yourself, either by conducting an experiment yourself or a situation where you have a chance to express yourself on an issue, to have an opinion. [...] the science center serves as such a platform that enables a valuable meeting between scientists and non-scientists (Director_03).
>
> [...] our mission is to be a bit of a bridge between the world of science and society. We are supposed to be a kind of two-way communicator (Manager_02).
>
> [...] it is a place that constitutes a certain platform for meeting science and society (Manager_03).
>
> [Science centers are there] to keep up to date, to talk about relevant topics and important topics, well [they are] such a field for discussion (Manager_04).

In the above statements, the activities of science centers are described as connecting the world of science and society. Therefore, those who directly shape the operation of science centers believe that these places can bridge the gap between the world of science and the surrounding social world. Moreover, there are statements about building a mutual relationship between the two realities, which align with the tasks outlined in the Mechelen Declaration (2014), created by organizations that bring together institutions promoting science, such as Ecsite or the Association of Science and Technology Centers (ASTC). The Mechelen Declaration asserts that "Science centers are not simply places where visitors have nice learning experiences or a great time on a rainy afternoon; they are unique institutions that transform the way in which people of all ages think and act. Reinforcing the collaborations will advance issues related to the public engagement with science and technology at a higher strategic level than before."

[6] All statements were translated from Polish into English.

In the next section of this chapter, we present answers to questions about what might be important for influencing the operation of system codes, thus contributing to the democratization of science. This primarily involves showcasing science in action and, therefore, not excluding it from controversy.

5.3. Potential to present research practice and actual controversial issues

In discussing the opportunities presented by exhibitions, science center managers and exhibition developers emphasize the current need to foster attitudes based on independent thinking and research methods, which are egalitarian tools that enable everyone to find answers independently and verify opinions based on structured observation.

> As far as the science center is concerned, its role is to encourage people to discover the world on their own. That is, to encourage someone to find out more on their own, to overcome some kind of resistance or fear of science (...) to break the negative stereotype (External Exhibition Developer_02).

> In Europe, these are the places that are supposed to explain what science is, show how interesting it is, show how it relates to society, this sense how people who are not scientists can benefit from science (External Exhibition Developer_03).

Moreover, we can assert that in the respondents' statements, participatory approaches to science communication are accompanied by the assumption that science and technological innovation are non-problematic goods.

> We should broaden people's views. How vast science is, where it is applied, how much it develops, and why it is needed because it is also a social role. Without the development of science, there will be no development of the economy. There will be no development of us (Director_01).

This promotional attitude may hinder the introduction of issues related to the background of scientific research, which are subject to technical, financial, and social constraints. Secondly, it may create reluctance to raise controversial topics, which could be problematic for science's "promotional" face. The exhibitions focus on objective scientific findings[7]. Nevertheless, a challenging attempt to present the social context of science and possible biases in research work is described by Pedretti and Iannini (2020) in the example of the exhibition "A Question of Truth" presented by the Ontario Science Center.

[7] There are examples of exhibitions that problematize technological progress, such as the aforementioned "The Future is Today" exhibition at the Copernicus Science Center in Warsaw. This is one of the few exhibitions that not only discusses the technical possibilities created by digital innovations, but directly raises questions about unresolved social issues. It seems to be a good example of an exhibition stimulating social debate around technological innovation. We can consider such exhibitions as precursors to problematizing the image of science. It might be interesting to study the public reception of this exhibition.

Generally, visitors have the opportunity for empirical experience or direct observation of selected closed research findings but lack the opportunity to make judgments, such as the validity of conducting research on a particular issue. There is no sticking point for discussion. This articulation of the science-society relationship can be described in Luhmann's terms and simultaneously provides a foundation for the independence of science (Taschwer, 1996, p. 227; Marcinkowski & Kohring, 2014). The relationship is therefore close and indispensable, but the direct tool for influence or control is missing.

In Luhmann's view, the impact of the environment on the system is possible only when circumstances significant to the operation of the system are altered (in the case of science, for example, affecting the way data are collected, which in turn can lead to the formulation of new scientific concepts). A participatory approach to science communication requires the recognition of areas meaningful for the system. If we present science as done, classical, and devoid of controversy, there is no way to influence it; it occurs independently based on its own mechanisms.

The relationship between the visitor and the science center exhibitions is based on occasional contact. According to the Copernicus Science Center Annual Report for 2017, more than 63% of visitors were first-time visitors, while for a further 22%, it was their second visit. This rate appears similar in the 2022 report, with 57% of people visiting the exhibitions for the first time and nearly 23% for the second time, which may also relate to the successive years of the center's operation (since 2010). However, the data indicate that the science center is not a place visited regularly. Therefore, such a relationship poses challenges in creating a platform for debate and the exchange of ideas or experiences.

We posited that showcasing unfinished science—science that is undergoing change—could prompt debate on research. In the interview, respondents were asked questions such as, "To what extent can a science center (within the space avail visitors) reflect the reality of a laboratory or research facility functioning within scientific institutions?" and "Is the science center exhibition a venue for discussing the dangers of scientific and technological progress, including controversies (why or why not, with examples if applicable)?" We posited further that learning about the realities of researchers' work can enhance public awareness of contemporary scientific practices. This understanding also facilitates the formulation of questions by relating them to direct observations and distinguishing between science and research. In the second question, we assumed that controversies could complicate the public's perception of science and illustrate the complexity of scientific problems. We can illustratively compare this to the adhesion of two materials that we would like to bond (or establish a relationship when we talk about science and society). Surfaces that are matte and full of fine irregularities have more adhesion and can be glued together more easily, while smooth surfaces are easily separated.

The respondents—individuals responsible for the strategy of science centers or creating interactive exhibitions—disagreed or indicated very limited possibilities when asked about the potential for presenting the realities of scientists' work in exhibitions. They highlighted the distinct roles played by a laboratory and an institution like a science center:

> The work of a scientist is more than carrying out one experiment, more than carrying out a series of more or less, but unrelated, experiments; so in this sense, it gives some flavour, some elements; we try in our exhibitions [to do so], but in my opinion, this is a feature of very few exhibitions in the world (Director_03).

> We do not aspire to this [...]. The laboratory is bound by a different work regime since it serves a different purpose (Manager_01).

> I believe it's probably almost impossible to accomplish. And we never, well I wonder how we would do it. Well, we probably won't be able to come up with it on our own, the researcher himself, whom we invite, won't be able to come up with it either, because they are a researcher, not a showman (Manager_02).

> No, it is not possible. [...] First of all, a researcher tinkers with detail for months or years. [...] but the biggest difference is that the researcher does not know what the result of their work will be (External Exhibition Developer_03).

One comment regarding the practice of setting up the laboratory in the exhibition space suggested that it lacked practicality:

> We do not plan it in this form, (...) we do not want to pretend that we have a research laboratory either. I agree that this is a certain direction, but frankly (...) what if I see that something is happening? I will not find out much (Director_03).

This comment was accompanied by a sceptical reflection on similar examples in other countries:

> So, there were also places where you could look at the researchers through the glass. The researchers did everything to protect themselves from that because it just disturbed them and distracted them, so they covered the glass and taped it up (Director_03).

In our interpretation, these statements address the challenge of combining effective scientific practice with effective science communication. The researcher aims to acquire new knowledge efficiently, making professionalization and specialization in a narrow field desirable. This naturally contrasts with what is popular and accessible to the public. Conversely, recipients of science communication, who specialize in entirely different fields, can expect answers to specific questions characteristic of various social systems. From such a perspective, the idea of introducing glass laboratories into science centers and museums (Wylie, 2019) is not considered a default method for presenting research

practice. Firstly, it does not facilitate the work of scientists (who are "researchers, not showmen" (Manager_02)), and secondly, it may convey a message that is too high resolution ("tinkering with details" (External Exhibition Developer_03)) for individuals not engaged in research daily.

At several exhibitions in Polish science centers, visitors occasionally have the opportunity to meet scientists who present elements of the research apparatus or answer questions concerning specific displays. In a few instances, respondents referred to laboratory sessions and meetings as opportunities for visitors to experience the researcher's perspective. However, such forms of activities do not accurately reflect the reality of a scientist's work on current issues. An analysis of the offerings in science center reveals that workshops are primarily aimed at children and follow predictable, scheduled scenarios. In contrast, the actual research process is characterized by uncertainty, failed attempts, and the constant emergence of new research threads.

The possibility of presenting scientific controversies related to current topics in the form of an interactive exhibition also received a predominantly negative response. Technical considerations related to the "inflexibility" of exhibitions:

> [...] the science that's happening here and now is changing very quickly, so if we were to show some elements from the science that are controversial now, then in a few years, that controversy could be in a completely different direction (Director_01).

Secondly, the respondents also raised the problem of reviewing and ting the materials provided by the science centers, which would have to be updated:

> The form of the exhibition itself does not really support this. In contrast, the form of an art exhibition, where you can rely more on artistic impressions and controversy and less on a solid transfer of knowledge, absolutely does (Director_03).

> Reliable verification of which information is (...) under investigation, which is a fake, which is an overinterpretation (...) is indeed not our role (Manager_02).

Thirdly, promotional considerations are crucial for these institutions, which serve as venues for family leisure and entertainment. This is particularly significant, given that most of the establishments in question are part of local government structures, leading them to avoid sensitive topics unless they directly concern the local community, as these may also pose publicity issues. This illustrates how the local political system, in Luhmann's sense, operates within a single organizational entity alongside other systems.

> [...] we rather want people to leave this place not sad, not depressed, not desperate, but rather intrigued, smiling, and with fond memories of their visit here (Manager_04).

> Controversial topics require a totally different environment and different surroundings. Therefore, yes, the science center should definitely engage with

> this. However, given the nature of the exhibition, the expectations surrounding it, and what it needs to provide to ensure people leave happy, it's usually very difficult to create such an exhibit (External Exhibition Developer_03).

Fourthly, according to respondents, presenting controversial issues in exhibitions does not provide a comprehensive view of the topic. Interaction with a single exhibit is often brief and superficial; visitors generally do not read extensive descriptions (as also indicated by research in Poland (Iłowiecka-Tańska, 2017, p. 32)). According to respondents, discussing controversial issues requires a comfortable setting:

> There are moments when we want to engage our visitors in discussion, forums, and meetings, and this is when it is worth discussing, talking about it. More than simply announcing it as a message or poster in the exhibition, saying "Now pay attention to this" (Manager_03).

> If something stirs up controversy because it evokes emotions, such as fear, then you really need to create an intimate, comfortable environment for discussion, for opening up, for listening to responses, and for reflection. It's not an interactive exhibit where there's noise, and people are jumping, playing, laughing, and so on (External Exhibition Developer_03).

> [The science center] is a place for serious discussions about science. However, this is not feasible in exhibitions (…). First of all, we have lectures. (…) We try not to frighten people with science too much, but more serious topics do arise. However, it is challenging to include them in an exhibition. (Manager_01)

The last quotation refers to lectures, one of the more traditional methods of presenting controversial issues in the scientific realm. However, lecture enables only limited forms of interaction. This operational model is summarized by Meyer thus: "Visitors are supposed to learn and ask questions about nanotechnology without, however, being allowed to engage and participate in actual research work" (Meyer, 2011, p. 269). This highlights the presence of the education system within a single institution (Baraldi & Corsi, 2017).

In the interviews, the personal predispositions of individuals involved in popularizing science also emerged:

> It is all very well to discuss presenting different topics from various perspectives, presenting threats and opportunities from different angles, but sometimes it is very difficult to achieve. Not so much in terms of demonstration, but science museums and centers are staffed by science enthusiasts, right? For me, for example, organizing an exhibition about how fascinating science is can be a great thing because it aligns with my views (External Exhibition Developer_02).

The unpopularity of the notion that exhibitions are suitable venues for communicating the controversies and uncertainties of science and technological

advances is confirmed by the almost complete absence of such exhibits. Respondents from several large science centers, estimated to have over a thousand interactive stations in total, identified and generally characterized only some particular exhibits that they felt touched on controversies related to technological developments. Two respondents, representing different institutions, referred to the same example of a stand involving listening devices. At this stand, visitors, acting as eavesdroppers, are introduced to three probable scenarios and can then "vote" (by inserting tokens into transparent containers) for or against the use of listening devices[8]. Additionally, the interviews referenced exhibits that describe topics such as ecology or research on human embryos. Respondents noted the unrestricted interpretative possibilities available to visitors regarding neutral technical innovations, enabling exploration of the multidimensionality of scientific research.

The exhibition's wide accessibility aligns with the idea of broad science (Sismondo, 2010, p. 173). From the other side, the more diverse the audience, the less specialized language that can be employed to describe particular issues. This necessitates simplifications that may be uncomfortable for researchers (Cameron, 2011, p. 97; Sismondo, 2010, p. 170), which in turn may contribute to the ambivalent attitude of the scientific community towards popularization efforts (Peters, 1995; Sismondo, 2010, p. 170-174).

In the interviews, only a few representatives of science centers did not express concerns about attracting active scientists for collaboration. Often, difficulties were indicated:

> There are not many sceptics, but there is sometimes disapproval within the scientific community towards the world of science popularization. The scientific community prefers to communicate in a scientific language, which, unfortunately, is not understood by the general public (Director_04).
>
> We do, of course, collaborate with scientists, but it is based on personal connections; we select those science enthusiasts who wish to share their stories about their work in laboratories, but it is not yet a systemic approach (Manager_02).
>
> Sceptics can be found among some scientists who believe that this manner of talking about science is an oversimplification, arguing that we pay a high price for this simplification and for making science more attractive by losing some important features of science (External Exhibition Developer_03).

[8] The description of this interactive station on the manufacturer's website: "The issue of eavesdropping touches on social, ethical, and legal issues. The exhibit draws attention to the possibility of employing listening devices for a variety of purposes. It prompts us to think about the circumstances in which eavesdropping is appropriate" (http://polaczsie.pl/eksponaty, accessed 20.04.2021).

Occasionally, respondents mentioned exhibitions intended for future presentation (currently under development). However, their final form remains difficult to predict. It appears that the assumption of the wide accessibility of exhibitions paradoxically hinders the implementation of dialogical and participatory models of communication. This is not something that determines the deepening of mutual relationships.

6. Discussion

This work investigates facilities operating in the science communication domain as part of the science system, based on the true/false code in Luhmann's framework. This theoretical approach enables us to consider science as a system differentiated from its external environment and as it is, operates only on its own code. This implies that each equivalent system must refer to the specific codes of other systems to elicit the desired response. Consequently, we assert that direct exchanges of perspectives between functionally differentiated systems are challenging to implement. Science centers exemplify this phenomenon.

By their very nature, science centers are strongly oriented towards activities that deepen the relationship between science and the environment. That can be seen in staff declarations and documents produced by organizations that connect similar facilities. As important institutions of science communication, science centers are undergoing continuous transformation (Pedretti & Iannini, 2020), yet interactive exhibitions remain their primary operational form. Observations and interviews reveal that, organizationally, science centers can combine the operations of different systems (such as science, education, and economy) in Luhmann's sense. For analytical purposes, in this paper, we focus primarily on the dimension associated with being part of Luhmann's system of science. Using Luhmann's theoretical framework, we are able to see why, in practice, they struggle to bridge the gap between the worlds of science and non-science.

Our respondents assert that they perceive their institutions as platforms for dialogue and two-way communication between science and non-science. To analyse this claim through the lens of Luhmann's autopoietic systems, we sought to verify the extent to which science centers can provide tools for mutual understanding between science and the environment. In practice, the primary operational form of the investigated facilities is stable exhibitions, where visitors view a "purified" world of scientific experience. It appears that exhibitions showcasing science in action, science accompanied by controversy, or the reality of a researcher's work are still rare. This corresponds with model assumptions how independent science functions to obtain new knowledge (Luhmann, 1989, pp. 76-77). To elucidate why discussing issues associated with processing science in social reality—under a continuous interpretative process where boundaries are sometimes blurred and many interdependencies are either not

apparent or very complex—is vital for dialogue and participation, we quote Horst and Michael (2011: 288): "It can be difficult to create dialogue and participation around a discussion of stable and uncontroversial facts."

In science centers, we will probably not observe how non-substantive reasons influence the choice of research tools (such as publication or patent potential, research team skills), how some researchers question the findings of others, what motivations drive the research directions adopted by individual scientists, how the research apparatus is arranged, or how statistical data are presented or omitted (Knorr-Cetina, 1981; Knorr-Cetina, 1983; Latour & Woolgar, 1986).

The reasons cited in the interviews to justify the omission of controversy from exhibitions imply that the entertainment context plays a significant role in shaping the profile of the science center as an entity that also encompasses elements of the political and economic system in Luhmann's sense. Most of the obstacles described in the interviews stem from the characteristics of cultural institutions that aim for high popularity and attendance in a commercial sense (such as technical issues, a joyful atmosphere, and superficial engagement with exhibits). Drawing an analogy with a zoo, it could be argued that the real natural world is not represented there either, such as animals attacking or eating each other, or merely being unpredictable. It seems challenging to incorporate discussion-provoking elements into an interactive exhibition, not only due to organizational conditions (where wide accessibility imposes a maximum of simplicity and limited content flexibility).

We can observe indications of a promotional role, particularly in the statements of exhibition designers. When technological progress is viewed as a path to sustainable development, science communication appears to be oriented towards the "selling of science and innovation" (Horst et al., 2017, pp. 892–893). That, in turn, places science centers in a competitive situation with other institutions operating in the field of entertainment and leisure. This phenomenon is not unique to Poland (Achiam & Sølberg, 2016). Nevertheless, it seems that the pursuit of high attendance, an important indicator of social usefulness, shapes the operation of science centers within market realities. Consequently, they often present an idealized image of science, divorced from the social factors influencing the individual disposition of researchers, the organizational context of research teams, and the material conditions under which research is conducted. An exhibition, therefore, does not depict actual science in action, as it is too fragmentary, and the exhibition space is technically challenging to change. Moreover, some respondents' statements indicate that a detailed presentation of a scientist's work is not significant in the visitor's experience. This discrepancy arises because visitors' goals concerning the exhibition differ from those of engaged researchers, which is also well reflected in Luhmann's concept of system codes (true/false).

We can assume that established scientific facts, largely devoid of controversy, error, and context, do not foster a space for debate that could guide, regulate, or support the development of science. Even if some signals for the system emerge, they are often too weak or scattered to be recognized systemically. This does not create a relationship that would allow, even indirectly, for shaping the connection between the science system and its environment, thus enabling dialogue or participation in science. We are witnessing an attempt to transfer the reality of the laboratory and research space outside traditional scientific institutions (e.g. research institutes, universities), but based on principles developed by science, where the reproducibility of experiments is guaranteed. Science interacts with the environment, but only to the extent that it allows for operation on a true/false code.

Using Luhmann's theory, we can also posit that the systems constituting the environment do not function as a unified organism. Meanwhile, a broad understanding of the audience in science communication entails a significant degree of public generalization.

A slightly different opportunity may be offered by citizen science, particularly in the case of local community issues necessitating involvement in the decision-making process. Such an initiative has the potential to enhance understanding of science, as individuals can develop research questions and participate in data interpretation or dissemination of results (Bonney et al., 2016, pp. 8-9), but this is feasible only based on the true/false code, where members of the public adopt the perspective of the science system.

7. Summary

Employing Luhmann’s approach, this article aimed to assess the extent to which institutions of science communication, such as modern science centers, can stimulate dialogue and participation in science. The relationship between the science system and other systems necessitates the creation of conditions that enable non-science systems to recognize and simulate elements of the science system, which, following self-referential system selection, will facilitate the democratization of science.

Considering Luhmann's concept, science centers (and probably most of other forms of organized science communication) cannot function as regulators between science and the environment. From the perspective of a particular system, the environment remains a homogenized entity, and as such, is unable to regulate the operation of the system.

In our specific case of science center operations, the majority of activities do not provide opportunities to influence the science system. The interactive exhibition only occasionally engages with the system selections of science, such as

in the field of educational research. Conversely, there are also limited opportunities to enhance the readability of the science system to the environment.

The respondents indicated that, in principle, presenting the realities of a scientist's work is not a goal pursued in interactive exhibitions at science centers. Although exhibitions are useful in making certain natural and technical relationships apparent, they offer little insight into how certain scientific facts are established and the social conditions under which scientists operate, which may be relevant to the functioning of science as a system.

In the respondents' statements, the ability to physically engage with the exhibition is highly valued due to visitors' claimed capacity for independent exploration. However, this engagement does not play a significant role in implementting dialogical-participatory models of science communication.

The respondents distanced themselves from the presentation of controversial topics in exhibitions which inevitably accompany the development of science. Scientific controversy tends to be regarded as an issue for discussion in smaller audiences, deemed inappropriate for inclusion in widely accessible expositions.

It appears that the interactive exhibition, in most cases, represents the deficit model in science communication, portraying science as a series of repetitive experiments that confirm established, neutral laws of nature. Further comparative research would enable capturing how this is perceived by recipients of the science centers in light of systems theory.

Ethnographic approaches present in science and technology studies have illustrated the organizational relationship of sciences to other social contexts but do not demonstrate their systemic separateness. Luhmann's approach allows us to show better the general barriers associated with the endeavour to democratize science. It is not about the extraordinary, in the sense of the superiority of science, but rather about its specificity, which is inherent in any separate system, such as law, economics, or education, which remain in relation to science but operate with their own codes. The barriers evident in conducting science communication are not merely mental or organizational; they are fundamentally the result of differing approaches that cannot be easily overcome, despite the organizational interconnectedness of various stakeholder groups.

In our view, other examples of scientific communication that either deepen or leave unchanged the science-society relationship can also be elucidated through Luhmann's concept of social systems. This theoretical approach effectively underscores a problem that remains relevant regardless of the form of science communication adopted. Some exceptions may be found in specific instances of citizen science, which may indeed represent the actual seeds of a participatory turn.

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