https://doi.org/10.22364/atee.2022.38

Spatial Reasoning Skills as a Universal Learning Outcome

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ABSTRACT

Over the last decades, the importance of spatial reasoning skills in all areas of life, including education, has received increasing attention while at the same time recognizing the need for solutions to organize learning processes to foster spatial reasoning skills.

Connectivism learning theory emphasizes the importance of an individual's ability to navigate today's information space in the learning process. According to Connectivism, to learn is to create a microsystem of personal learning within the macrosystem of society by creating a Personal Learning Environment to promote learning autonomy and self-regulated learning strategies.

Implementing Universal Design principles in education provides a theoretical framework for an inclusive educational solution based on respect for each learner's unique learning and strategies, as determined by innate abilities and experiences gained through interactions with the environment and society. This study aims to explore the possibilities of modeling the educational process using a Universal Design approach and principles in the context of Connectivism learning theory, focusing on spatial reasoning skills as a prerequisite for diversity and developing an organizational process-oriented model to foster spatial reasoning skills as a learning outcome. The developed model of study organization has been validated in a design study process; the results allowed for the creation and justification of recommendations for using the research results in other study programs and future research.

Keywords: Connectivism learning theory, educational process, learning outcome, spatial reasoning skills, Universal Design

Introduction

One of the primary purposes of 21st-century education is not only to master new knowledge but to administer the process of mastering this knowledge as well, for learners to become experts in studying and persons who are eager to

study and can perform the learning process in a strategically and individually unique mode, thus becoming lifelong learners.

"Space is the basic component of our cognition" (Ishikawa & Newcombe, 2021) and spatial reasoning enables us to collect the results of spatial thinking not only to solve the adaptive task of grasping, analyzing, and forming conclusions about the information obtained but also by mentally structuring, combining, or otherwise transforming it, to creatively develop new solutions and spatial combinations (Newcombe & Huttenlocher, 2003). The skill to reason and operate in diverse situations according to the decision has been mastered all lifelong. The obtained experience is one of the essential preconditions of diversity. Concerning the learning process, it can be concluded that students have different spatial reasoning skills at the start of their studies, determined by a combination of individual abilities, age differences, and the circumstances (family, socio-cultural environment, previous education) in which previous spatial experiences were formed.

The Universal Design principles (Mace, 1997), which articulate a user-centered and inclusive design approach, provide a conceptual framework for implementing student-centered learning environments, recognizing diversity as the norm rather than the exception.

Research shows that the way people learn is authentic and, at the same time, changeable, learnable, and improvable through the learning process. The method or strategy of learning is determined by innate abilities and acquired experiences (Zhang & Evans, 2015).

The processes associated with developing digital technologies in the 21st century have paved the way for a paradigm shift in education, providing opportunities to learn in before previously impossible ways (Siemens, 2005). The space in which we acquire knowledge has expanded, from the school as a physical place in the 19th century where "knowledge is acquired" (Barr & Tagg, 1995), to the digital intellectual environment of the 21st century (Siemens, 2008). Connectivism learning theory emphasizes the importance of navigating information space in the learning process, arguing that learning in today's context of information diversity enabled by information and communication technologies means learning to navigate between these points of connection (Downes, 2019).

Education is a multidisciplinary field, but it must be acknowledged that several disciplines do not imply a transdisciplinary approach (Choi & Pak, 2007). As a significant disadvantage of scientific research on spatial reasoning over the centuries, it reveals a significant gap in research on how "spatial reasoning" is understood and studied across academic disciplines. The first historical map produced shows the evolution of spatial reasoning in major scientific fields, where it is evident that educational researchers do not include the vital work of psychologists and neuroscientists and vice versa (Bruce et al., 2017, p. 4).

The authors of this study argue that a greater emphasis on transdisciplinary research maybe be timely, and perhaps even necessary, in the evolution of educational research" (Bruce et al., 2017, p. 1).

This study aims to construct a theoretical framework to explore the possibilities of modeling the educational process using the Universal Design approach and principles in the context of Connectivism learning theory, focusing on spatial reasoning skills as a prerequisite for diversity.

Methodology

An integrative literature review method was used to achieve the study's aim. An integrative review approach can be useful when the purpose of the review is not to cover all articles ever published on the topic, but rather to combine perspectives to develop new theoretical models (Snyder, 2019). Unlike a semi-structured review, an integrative review often aims to assess and synthesise new knowledge, weaving together ideas from the literature on the research topic to create the basis for a new theoretical framework in a unique synthesis model (Torraco, 2016). The review followed a conceptual structure, focusing in this article on spatial reasoning and the possibilities of promoting spatial reasoning skills in the organisation of the educational process. Literature on spatial thinking and the promotion of spatial reasoning in the organisation of educational processes were selected for review only if it met all of the following criteria: books and peer-reviewed scientific journal articles dealing with spatial reasoning as an essential prerequisite for individual diversity, especially for achieving learning outcomes, were selected for review. Articles in non-peer-reviewed scientific journals and non-professional publications were excluded from the review. Publications, books and journal articles on spatial reasoning published in the last 40 years (since 1983) were selected for review. Publications that met the above criteria were selected for review in Cognitive Psychology and Education (Universal Design in education and Connectivism learning theory). A holistic approach is utilized, integrating findings of cognitive psychology, implementation of the principles of Universal Design in education, and Connectivism learning theory, to establish correlations.

Literature review

Firstly: the study provides some essential insights into significant research findings in cognitive psychology.

It is important to emphasize that the concept of space encompasses physical and intellectual domains and their representation and interaction over time and that spatial reasoning skills help not only to structure and organize but also to analyze

and explain the vast amount of data that we can acquire and store in memory (Downs & DeSouza, 2006). Research in cognitive psychology and neuroscience, well documented in the scientific literature, shows the diversity of processes involved in spatial thinking. In space and time, spatial reasoning is a tool for determining spatial relations between the static and the dynamic, between the self and other objects and entities in space. It is itself a complex and dynamic process that allows us to describe, explain and predict the structure and function of space in both real and imagined spatial environments, as well as to generate hypotheses, make predictions and define possible consequences (Downs & DeSouza, 2006). However, how we learn about a space acquires a symbolic sense of meaning in our understanding, and the context of the space, and at the same time the social situation in which we receive the information, is a determining factor in shaping comprehension, meaning, and significance (Newcombe et al., 2013).

Moore-Russo et al. (2013) define spatial literacy, i.e., spatial reasoning skills, as the organization of the spatial thinking process and conceptualize three functional domains involved: visualization, reasoning, and communication, which overlap and influence each other (Moore-Russo et al., 2013). Spatial reasoning is both an internal mental process involving visualization and argumentation and a public process that is communicated in three primary ways: graphically, kinaesthetically, and verbally, using spatial information code systems (graphics, body language, verbal communication) as tools (Downs & DeSouza, 2006; Newcombe et al., 2013).

Spatial skills are malleable and can be enhanced: even a small amount of training can improve spatial reasoning skills for everyone, regardless of age or gender, and in a purposeful learning process, the levels of spatial reasoning skills converge; therefore, spatial training programs can play a vital role in education (Uttal et al., 2013).

The ability to reason and infer using spatial patterns and structures is essential in many arts and sciences. Spatial reasoning skills are needed in every field of knowledge, especially medicine, physics, education, and design (Lee & Bednarz, 2012), yet its importance in learning is under-recognized and under-valued (Downs & DeSouza, 2006).

In order to identify spatial objects and understand the properties of and relationships between objects – hence to promote spatial reasoning, Golledge (2002) emphasizes the importance of the concept of language as a code for spatial information and suggests organizing the learning process sequentially from the simplest to the most complex:

- start by clarifying the basic concepts,
- to add individual spatial concepts, skeletonizing the overall relationships,
- demonstrate how a spatial concept is formed from the aggregates,
- engage students in independent reasoning (Golledge, 2002).

The scientific literature suggests that the process of studying spatial contexts and spatial examples can be a variety of learning processes organized through the use of spatial contexts in both the presentation and discussion of information:

- promotes spatial thinking and reasoning (Terlecki et al., 2008),
- enables learning outcomes that are robust, long-lasting, and at the same time flexible in their application to different problem-solving situations (Mohler & Miller, 2008; Sorby, 2009),
- is efficient and can reduce the time required for learning in any discipline (Rovet, 1983).

Summarizing the theoretical findings related to the promotion of spatial reasoning skills in the study process, three essential conditions for the development of spatial reasoning skills:

1. Comprehension:
   - context of information (Glass et al., 2013),
   - accurate and justified use and explanation of linguistic concepts,
   - verbal communication is supported by graphic diagrams, pictures, spatial patterns, and appropriate gestures) (Newcombe et al., 2013);

a study process that provides a varied display of information provides comprehension of space in the context of the social situation, which is the first essential condition for developing spatial reasoning skills;

2. Opportunity:
   - the right to an opinion (*students' voice*) (Toshalis & Nakkula, 2012),
   - active engagement,
   - use of own learning strategies (Mann, 2006);

the opportunity for multiple involvement and participation in the learning process according to the diversity of students' learning in time and space is another essential prerequisite for promoting spatial reasoning skills.

Toshalis and Nakkula (2012) argue that without engagement and "voice," there is no authenticity in learning, and without motivation, there is no incentive to learn (Toshalis & Nakkula, 2012).

Neuroscience research shows that if the experience is gained through active engagement. A student-centered learning process enables students to engage in active learning experiences and thus becomes relevant to their everyday lives (Hinton et al., 2012).

3. Motivation:
   - establish task value,
   - promote mastery goals,
   - promote belonging,
   - promote emotion regulation,

- promote expectancy for success,
- promote autonomy (Belland et al., 2013);

Secondly, the study explores how the implementation of principles of the Universal Design in education correlates with the findings mentioned before to facilitate the students' spatial reasoning skills.

At the turn of the 20th and 21st centuries, Universal Design principles were adapted to education through several models, including Universal Design for Learning (UDL) (Rose, 2001; Rose & Meyer, 2006); Universal Design for Instruction (UDI) (Shaw et al., 2001; Scott et al., 2003), and Universal Instructional Design (UID) (Silver et al., 1998). These are not in competition with each other but rather complement each other (Higbee & Goff, 2008). The three theories mentioned above are often cited in the literature as a conceptual framework for accessibility in education to create inclusive learning environments for all students (Rao et al., 2014).

The principles developed in UDL, UID, and UDI focus on the organization of flexible teaching and learning processes to meet the diverse needs of students (Hall et al., 2012).

Summarizing the insights and principles developed by all three theories, it can be concluded that the implementation of Universal Design principles in the organization of the study process is characterized by:

1) an inclusive and welcoming learning environment based on respect for the individuality of each person, recognizing student diversity as the norm rather than the exception, with an emphasis on fostering an understanding of personal responsibility for the decisions made:
2) diverse opportunities for action, cooperation, interaction, and communication,
3) versatility of material presented,
4) the activity of the lecturer – assessing the relevance of his/her approach to the diversity of the students.

The study reveals how theoretical insights on promoting spatial thinking skills relate to the principles of Universal Design in education according to contemporary learning theories in a diverse open-access information space.

Summarizing the theoretical findings related to the promotion of spatial reasoning skills in the study process, it can be concluded that a supportive study environment and lecturer's actions, which correspond to the diversity of students, create prerequisites that enable students to make spatial judgments in communication (diverse communication opportunities) and to develop an understanding of spatial information in the context of the social situation (diversity of presented material), as well as encourage each student to develop personal awareness and attitudes (see Figure 1).

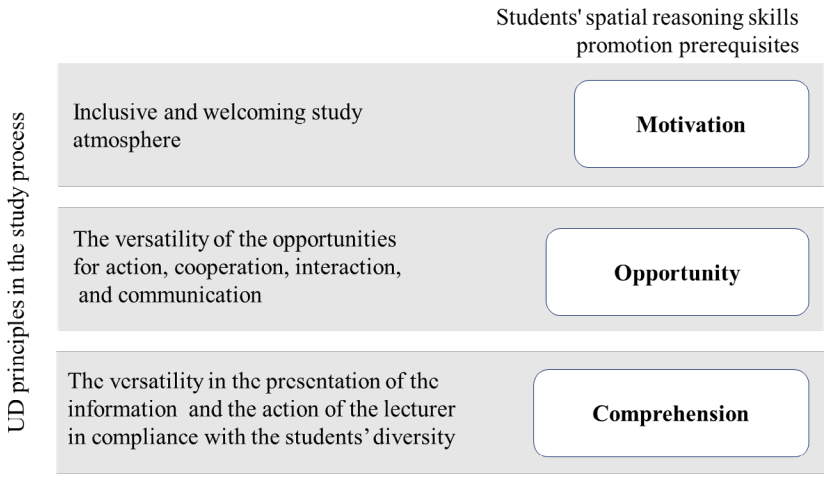

Figure 1. Student spatial skills-enhancing study process, Author's concept

Thirdly analyzing the main concepts of the Connectivism learning theory study investigates the factors that determine the learning required in today's complex and fast-changing information environment where an almost unlimited amount of knowledge is available (Downes, 2019).

According to Connectivism understanding, the starting point of learning and knowledge is the individual or the subject. The knowledge of the subject is a multimodal structure and is formed in interaction with the social environment and society, which in turn becomes an object in the social environment and influences the development of knowledge (personal network organization) of other individuals or subjects (Siemens, 2005, p. 2). Connectivism provides a rationale for the learning that is needed in the new digital age and the tasks that need to be undertaken in the learning process so that students not only acquire knowledge, skills, and competencies but also know how to use them in different social and cultural spaces, transforming them into new situations (Kersh et al., 2012) while promoting learning autonomy and self-regulated learning strategies (Schmidt et al., 2013). Connectivism learning theory emphasizes that acquired knowledge finds meaning in a context that shows the relationships between individual facts (Siemens, 2008; Downes, 2012).

Moreover, the tasks that need to be undertaken in the learning process so that students not only acquire knowledge, skills, and competencies but also know how to apply them in unforeseen situations in different spaces of social and cultural life and activity. Connectivism learning theory emphasizes the importance of the individual's ability to navigate the modern information space creating a unique

Personal Learning Environment (PLE) to promote learning autonomy and self-regulated learning strategies. The principles of creating a PLE and its implementation in the learning process according to Connectivism are characterized by five aspects (Downes, 2007) (see Table 1).

Table 1. Personal learning environment, Author's concept

Nr.	Principles	Implementation tasks
1	Informative community	Providing links between diverse information sources/ objects
2	Creative activities	A creative approach, looking for new solutions rather than memorizing facts
3	Context of information	Assessment of the gained information in every situation
4	Support tools	Use of communication technologies
5	Diversity of participation	Opportunities for autonomy and choice

Results

The symbiosis of the insights of the Connectivism learning theory and the implementation of the Universal Design principles in education is an application of the model of the organization of the learning process focusing on spatial reasoning skills.

The organizational model of the learning process aims to provide an inclusive and receptive learning environment, respecting the student's existing spatial reasoning skills at the beginning of the study, which becomes a frame of reference and a starting point for learning and understanding new information. The result of an investigation of the Universal Design principles in education and principles of creating a PLE according to Connectivism learning theory provides the theoretical framework for creating an organizational process-oriented model to promote spatial reasoning skills as a learning outcome (see Figure 2).

The model developed as a result of the research is based on a symbiosis of the insights of Connectivism learning theory and the principles of Universal Design in education. The organizational model of the study process aims to provide an inclusive and receptive study environment, with respect for each student's identity or the student's existing spatial reasoning skills at the start of the study, which becomes a frame of reference and a starting point for learning and understanding new information. The student's personal learning environment, in which opportunities for collaboration, interaction, and participation are provided by the lecturer's assessment of the students' diversity and the demonstration of a variety of information, will shape the student's understanding of the context of the information acquired according to the social situation.

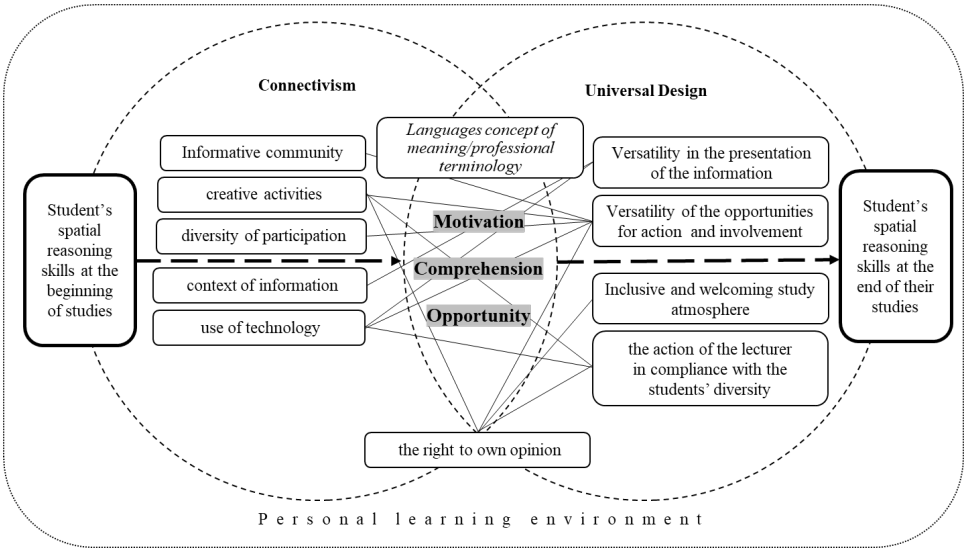

Figure 2. The organizational process-oriented model of studies, Author's concept

In contrast, the opportunity to communicate their unique judgment, experience, and creativity in the learning process will encourage the motivation to develop personal opinions and justify the decision-making process, promoting the student's spatial reasoning skills as a learning outcome.

Conclusions

Summarizing the theoretical findings on the promotion of spatial reasoning skills in the study process, it can be concluded that a study process that provides:

- the versatility in demonstration of information (the interconnection of sources/objects in context, also using the possibilities offered by digital communication technologies),
- versatility of engagement (autonomy and choice according to the diversity of students' learning in time and space, including the creation of a learning community within social networks),
- the opportunity for debate and the "right to your own opinion."
- a motivating, inclusive and supportive learning environment,

is grounded in Connectivism learning theory as an embodiment of the Universal Design principles in education and promotes spatial reasoning skills.

The developed model of study organization has been validated in a design study process; the results allowed for to creation and justification of recommendations for the use of the research results in other study programs and future research (Karlsone, 2017).

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