MIND, BRAIN, AND EDUCATION

Design of Learning Spaces: Emotional and Cognitive Effects of Learning Environments in Relation to Child Development

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ABSTRACT—The design of learning spaces is rightly gaining more and more pedagogical attention, as they influence the learning climate and learning results in multiple ways. General structural characteristics influence the willingness to learn through emotional well-being and a sense of security. Specific structural characteristics influence cognitive processes, from visual and acoustic perceptions, via attention to the model, to processes of comprehension and reflection. Aspects of the design of the learning space also modify the interaction among students and between students and their teacher. Furthermore, the different requirements that have emerged through the development toward a learning society and the explosive increase of available information in our society require changes in the design of learning processes and thus of learning environments. Taking biological needs and neurobiological processes into account when designing learning spaces can provide a beneficial learning environment with regard to mental resources. This article will highlight relevant (neuro)biological fundamentals and try to describe resulting conclusions for the design of learning spaces.

The extremely high adaptability of the human brain should not lead to the presumption that the circumstances under which educational and learning processes occur do not matter. Any adaptation requires the use of cognitive and emotional resources that are then no longer as much available for other processes, for example, the actually intended and relevant learning process. Accordingly, learning processes can be supported by ensuring that as few resources as possible are used for unnecessary, avoidable processes, such as adaptation to unfavorable conditions or orientation in poorly defined spatial or social situations.

THE CONSIDERATE TREATMENT OF COGNITIVE AND EMOTIONAL RESOURCES THROUGH ADEQUATE LEARNING ENVIRONMENTS

The evolutionary history of the brain explains why natural components of environments and architectures have a relieving influence with regard to mental resources. These components include the penetration of daylight, visual access to green spaces through a window, possibly direct access to the outside, spending comparatively longer periods of time outside every day, and having plants in the rooms and next to the building (see Bringslimark, Hartig, & Patil, 2009; Ulrich et al., 1991). When designing green spaces, the variety of plants is also important (Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007). Using natural materials, such as wood for the interior design, or concordant colors, or installation of soft, springy floors in some areas can create something close to a natural environment. The partitioning of the space into open, clearly laid out areas, and protected havens takes into consideration natural human preferences and thus conveys a feeling of security (Orians & Heerwagen, 1992). Where adequate, partitioning can also be realized with construction

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of several floors in a room. Children and adults alike consider the relieving effect of such measures to be subjectively relaxing (Herzog, Chen, & Primeau, 2002; Korpela & Ylén, 2007). This emotional relief can be shown through physiological parameters (decrease of pulse rate, blood pressure, etc.) (e.g., Parsons, 1991; Tsunetsugu, Miyazaki, & Sato, 2002). For children attention to learning often improves in natural environments (Faber Taylor & Kuo, 2009; Mårtensson et al., 2002).

The second important factor related to learning and to emotional balance is the previous experience people have had in their family, day care facility, and living environment, and the resulting assessment of (learning) environments. Already before entering school, a child's brain has integrated a lot of information through habituation and perceptual learning that leads to strongly anchored perceptions and expectations concerning architecture and spatial design. Without considering prior experience, it is impossible to say which elements of the design of learning spaces are associated with positive or negative experiences and which effect they have in each individual case. Generally, however, familiar elements convey a sense of security. Accordingly, implementing familiar structures has a supporting aspect, especially for younger children, for instance when they start primary school. For general architecture and general aesthetic perception, a common cultural and social background usually means that the students and the adults designing the learning environment will share similar perceptions. If they do not share these aspects, responsible adults need to pay particular attention to the problem and handle it consciously. Sensitivity to ethnic and cultural differences is anchored in various levels of social consciousness in different countries. While the consideration of diversity is already being discussed in pedagogy (e.g., Souto-Manning, Hanson, & Hanson, 2009), a discussion about its consequences for the design of learning environments is still outstanding. For this discussion to contribute to the design of learning spaces, the specific circumstances of each country or region need to be considered.

As most children entering primary school have previously attended day care facilities, it would be useful to examine whether aspects of the design of these facilities could be adopted in primary school. Apart from the home environment, these facilities are part of the child's most familiar environments and one could expect that the adoption of certain of their elements would give most children a sense of security. Another, also cognitively relieving possibility would be to adopt systems for classifying and storing materials that children already know from kindergarten or preschool. In both cases, a visit to the previously attended day care facilities could provide precious elements for the design of class rooms for the start of primary school. Although the specific organization of every day care facility can of course not be reproduced, it seems desirable to identify which key elements could or would have an identification value for the children, while making sure they are compatible with the school learning environment.

Age-Related Needs

The need for security in preschool children and at the beginning of primary school is a consequence of their dependence on the care of adults, especially in their social environment, and only secondarily in their spatial environment. Yet like many other kinds of behavior, this dependence also shapes the search for a secure spatial environment. As children and students grow older, they may depend less on familiar structures to feel safe. This is due to the increasing amount of experience with different kinds of surroundings, as well as the development of new competencies, such as emotional regulation. This does not mean that older children and adolescents do not attach any importance to security. It is simply transmitted less through factors such as familiarity and comfort, but instead through dimension such as orderliness and clarity (Zoller Booth & Chase Sheehan, 2008).

Preference for the design of environments as close as possible to nature seems to be related to natural visual preferences. These are not stable, however, through the course of development: For children of around 8 years of age and adults, studies have shown strong similarities in visual preferences (Balling & Falk, 1982). Thus subjective preferences of responsible educators can represent an adequate criterion for spatial design, especially when teachers' individual preferences are counterbalanced by the opinions of the entire teaching staff. The age groups of 11- and 15-year olds, on the other hand, seem to show diverging assessments of natural scenes from adults. Accordingly, involving youths in the planning of learning spaces would seem to be desirable instead of putting forward the aesthetic preferences of adults (Hinton & Fischer, 2008), when the purpose is to create an environment beneficial for learning and to consider cognitive resources as well as the needs of specific age groups (even if education to "beauty" might actually complicate the issue; see Gardner, 2011).

Furthermore, the preferred social forms of interaction and the relationship to adults, and thus teachers, change during the course of schooling. Children's ways of interacting with each other change dramatically during childhood, with play starting in small groups (e.g., pretend play). In primary school, social groups are created that have a great importance to social development. Often these groups are separated by gender (Largo & Beglinger, 2009). Textbooks from different countries supply different information on the size of these groups and their dependency on the sex of the children, so that it can be presumed that cultural differences and/or differences in possibilities of making contact (e.g., forms of day care) have an influence (e.g., Berk, 2002; Mietzel, 2002).

With increasing age and the increasing importance of the peer group, the relationship to adult caregivers changes. During early childhood adults also serve as role models, besides giving protection and a feeling of security, providing children with standards for their own behavior in unfamiliar circumstances. During primary school this dependency becomes less important, but the centrality of adults as role models and points of reference often stay the same, as do acceptance of adults' definitions of right and wrong, suitable and not suitable, and so on. In adolescence, the role model function and the acceptance of the adults' definitions become less important, as the youth grow up. This process is also culturally formed.

Yet it can be presumed for most Western countries that the role of the teacher changes considerably over time. They take on the role of a supplementary caregiver in primary school, to whom many children develop a strong and trusting relationship. But adolescents often challenge teachers. In the education of this age group, the much discussed change of the teacher's role from instructor to facilitator reaches a different level of importance. It is essential to consider their social and cognitive development. For the design of learning spaces the changing roles of teachers and students need to be considered.

The Learning Process as Such

Owing to the modified living conditions of modern societies, which among other things lead to the necessity of lifelong learning, the requirements of schooling have changed. Students today need to learn strategies to acquire new knowledge and competencies by themselves, and they need to learn to adapt these strategies to ever new situations and problems. To this end, different teaching forms have been developed which are, however, constructed on the limited number of learning forms accessible to students in schools and other learning environments.

Learning-by-Doing

One of the central didactic elements is learning-by-doing. As a form of learning, doing things on one's own is particularly suited to acquire competencies, for example, writing, reading, calculating, but also developing gross and fine sensory motor skills. This process needs to be distinguished from the acquisition of *rules* of orthography or mathematical formulas. It is more about being able to use those rules, concepts, and formulas. Depending on the curriculum, they are either introduced parallel to the acquisition of the actual competencies, or in modular steps before the next level of competence acquisition. But learning-by-doing is not only a way of acquiring competencies. Instead, experiences made in that context, together with experiences from observations and daily experiences, are the essential basis for all higher order mental processes, such as developing concepts, testing hypotheses, solving problems, and so on (Williams, Huang, & Bargh, 2009).

Typical forms of learning-by-doing are learning through trial and error, and learning through models by observing and imitating. In both cases, the child must become active: An action is performed, the result is verified, mistakes are corrected, and future performances are bound to be more successful. When an action is successful and the desired result is achieved, the brain's reward system is activated. A larger quantity of released dopamine leads to a stronger connection between those nerve cells that have just been activated. These connections store a representation of the successful action procedure and can then be called upon in the future. At the same time, positive emotions (e.g., joy) are triggered through the dopamine release, and motivation is increased. In order for the reward system to be activated, it is necessary for the learner to know immediately, or within a few seconds after the end of the fulfilled action, whether it was successful or not (Fiorillo, Newsome, & Schultz, 2008).

Inevitably, when learning through trial and error, at the beginning there are regular failures. This is unavoidable, when a learning success is to be achieved, as the competence being practiced is not yet available. Moreover, a possible failure is an absolutely necessary condition for the release of dopamine and the effect described above, which increases memory functions. If the success of an action is expected, dopamine release does not occur, even if the procedure indeed succeeds (Mirenowicz & Schultz, 1994). But this certainly does not mean that an unsuccessful action should be related to further negative consequences of any kind. It is sufficient for the learner to become aware that the action was not successful. Further influences by the environment in this situation can lead to aversive consequences, such as reproach, mockery from other students, maybe a disapproving look for sensitive children, or even an inadequate effort to comfort the child after an unsuccessful activity, even if it does not need comforting. The effects of these consequences depend on how the child interprets the reaction to the lack of success. Aversive consequences can lead to refusal to try new things (e.g., Mazur, 2005), which needs to be avoided, if actively learning by oneself is a learning goal. It is much better if students are made aware of partially successful results or that they were close to success, in order to help them make a successful outcome more likely.

The difference between learning through trial and error, and observational learning primarily lies in the information available to the learner. In the first case, the learning path and the procedure are often undefined, while the desired result (e.g., writing the letter "a") is possibly known. When observing, however, the learner is given information not only about the desired goal, but especially about the procedure, or at least about one of the possible procedures, and can then plan his own actions. Observational learning is supported by a specific group of cells in the inferior lateral frontal cortex, the mirror neurons, which represent actions we observe in other people (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). This representation allows us to directly integrate other people's actions into our regulation of actions (Buccino et al., 2004). While in monkeys, in which these nerve cells were first discovered, cell activity is linked to the existence of an object for which a movement is directed, in humans this representation also includes movements not bound to objects (Rizzolatti, 2005). In humans, these cells build the basis for the imitation of all possible movements. The existence of such a special nerve cell group indicates that observational learning has a specific value (van Gog, Paas, Marcus, Ayres, & Sweller, 2009). It is particularly remarkable that mirror neurons are not only active while observing and fulfilling actions, but also when actions are verbally described (Tettamanti et al., 2005). Although research is still young, it can be expected that this characteristic of mirror neurons contributes to the supportive effect of verbal descriptions of actions when people are learning competencies, as observed practically in daily life.

The learning mechanisms implemented in the brain do not indicate whether the person observed needs to be a teacher (teacher centered teaching phase) or another child, in classes with mixed age levels possibly a child of a different age group or competency level (pair or group work). When choosing a model, the learning goal is probably more important. If a most accurate result and an optimal and rapid action are to be achieved, it is wise to observe a true "expert." However, if a whole range of different results are to be shown, or are acceptable, it would be useful to observe people who are still learning themselves, or to directly initiate the principle of trial and error.

Similarly, neuronal activity in the acquisition of competencies cannot indicate whether repeated trials of an action are better performed by oneself, or in pairs or groups. This decision will depend on the learning content and the goal, as well as other factors, such as social and motivational issues. From a cognitive aspect it is simply important to make sure that every learner has enough time for learning-by-doing and for practice.

A very important factor in deciding between several learning arrangements (those that require learning through trial and error and those that rely on imitation in one way or another) is to consider the cognitive strain created by the arrangement (cf. Kirschner, Sweller, & Clark, 2006). In situations of imitation the action to be performed should be known, at least vaguely. However in trying something for oneself, a large number of actions are possible. With difficult, complex questions and/or little experience with similar questions from the learner, the variety can be very large. Trying to choose a procedure for action based on previous knowledge or actual information requires a parallel representation of different alternatives and their characteristics; this is a challenge for working memory.

This process is often abridged by making a spontaneous decision and "simply trying something" in order to obtain a result. This allows identification of actions that do not work but are still represented in working memory and stored there to avoid performing the same unsuccessful actions. This aspect alone makes clear that the process of "simply trying something" is not necessarily "simple." This is different when learning material is designed in such a way that it accompanies the learner closely, for example, by encouraging a particular type of action through its outward structure or through contextual support. In that case, the strain on working memory is smaller than with tasks that are not restricted. First, this means that with a specific type of task a familiarized learner has a lower cognitive strain because of his previous experience in learning through trial and error. Second, the teacher who structures the process needs to be aware of this difference in cognitive strain, modifying the task according to the limits of each student, and adopting possibilities for compensation, for example, through positive feedback, facilitating social forms, adequate pauses, positively designed material, and structured learning environments.

From Doing to Knowing

From a neuroscientific perspective, acquiring knowledge, which encompasses the development of concepts, categories, and schemata, represents a combination of cognitive processes and of learning-by-doing or observational learning (especially for preschool and primary school children).

Through learning-by-doing, not only are skills trained, but knowledge about relationships between actions and outcomes as well as environmental principles is acquired. To begin with, such processes are often related to children's playing activities (Sacher, 2004). Hypotheses, concepts, and the search for a way to express relationships, in other words what we call "understanding" (Gärdenfors, 2007), are constructed on this model of knowledge acquisition, on observations and experiences in daily life, and on the development of the frontal cortex (Luciana, 2002). The deeper understanding of learning contents that is sought, as well as their application to new situations and questions, grows from this process. The beginning of a conscious reflection in many children becomes obvious with the sudden increase of "why?"—questions.

Contrary to what is often believed, the maturation process of the frontal cortex (just as the maturation of other structures within the cerebrum) is not independent from learning processes: It requires, from the first months of life onwards, a stimulating environment and many frequent and diverse opportunities to act in a self-determined way. Modern kindergarten pedagogy strongly emphasizes the importance of self-determined action and discovery. The implementation of learning-by-doing in schools only deepens this process. The more freedom preschool children are given to choose both content and ways of implementing their learning, the more the course design is beneficial for the maturation process—whatever the related demands on the child's cognitive functions.

The second factor that decisively contributes to the development of knowledge structures is reflection about actions, observations, and coming to conclusions. In order to develop a sustainable knowledge base, it is necessary to organize and categorize life experiences. Only then is it possible to retain the amount of knowledge that one gathers throughout the life cycle and to keep this knowledge accessible in order to retrieve and use it in a suitable way whenever needed (e.g., Edelmann, 2001). Category-building appears very early in children's development, and is even observed in animals (Ohl, Scheich, & Freeman, 2000). Nevertheless, exchanges with others seem to play a key role for human beings when it comes to developing their cognitive representations.

The significance of exchanges, captured by the phrase "co-construction," has recently attracted attention. To begin with, this notion derives from the fact that knowledge, as we all know, is not simply "incorporated" but is rather constructed on the basis of incorporated pieces of information which have been turned into neuronal representations of what is experienced or perceived. This representation generally does not reproduce every detailed element or characteristic, but it makes possible the building of classification systems. The particle "co" in "co-construction" stresses that the process is not an independent one, but that it takes place in the interaction with others. This—often language-based—interaction supports cognitive access to the acquired pieces of information. It is considered as a system of reference for the construction of categories and concepts, and as a starting point for the processes of understanding (e.g., Berk & Winsler, 1995). Besides this cognitive viewpoint, it is obvious that social interactions and the related emotional components play a role in concrete pedagogical situations (Goldstein, 1999). It will be extremely difficult, if not impossible, to establish how far the cognitive, social, or emotional aspects of the learning process respectively contribute to successful knowledge acquisition. Knowledge is constructed by these three dimensions together.

Because of their incomplete brain maturation, primary school children often benefit more clearly from their own experience than from mere representations; and the younger children are, the more obvious this is. In order to stimulate cognitive processes, the instructor or teaching materials can offer explanations, and can help construct or verify hypotheses. The cognitive stimulation must happen in one way or another for the learning process to take place, and the instructor should be aware of the fact that not every child benefits the same way from various kinds of stimuli. As a result, combinations of cognitive stimulations are often privileged. In contrast to the acquisition of skills, the acquisition of knowledge contents clearly requires that learning-by-doing or observational learning should be the result of team work or take place within small groups. This form of cooperation leads to necessary exchanges, to common planning, and directly to a combination of learning-by-doing and observational learning, as well as to a growing awareness of structures, processes, and relationships expressed verbally.

The more basic knowledge that is acquired with age, the stronger these processes can be internalized and imagination can at least partially replace action and discovery. This imagination can, for example, also be triggered by a lecture or an introduction to a subject. The internal representation of procedures of action and the mental "construction of the process" is the basis for the conscious choice and planning of processes of action. The combination of such representations with the representation of problems and questions is the basis for problem-solving capacities. However, the knowledge acquired through repeated actions and experiences up until adulthood is the basis for a deeper understanding of relationships (Williams et al., 2009).

MINDFUL TREATMENT OF COGNITIVE RESOURCES THROUGH INTEGRATING LEARNING PROCESSES AND SPATIAL DESIGN

Examination of the learning procedures described above makes it clear that at almost every phase different working and social forms are possible. Learning-by-doing and observational learning are possible in individuals, pairs, and groups. In such learning school children need support from their teachers, especially when they are confronted with a completely new learning content. Spatial design in the learning environment must enable the teacher to get to each child or group easily. Moreover, each child should be able to work without being disturbed. The necessary calm can be achieved through general instructions (everybody is to work in silence and stay in their place) or through a visual and acoustic separation of individual and group work areas. Whether the children are sitting at, on, or under a desk, on the floor or on a couch has little importance for brain processes. It is simply essential that the child feels well emotionally and is not distracted, and that the necessary material and enough storage space are available. An important factor is the accessibility of material. To be successful, it needs to be stored in well-structured classification systems that students are familiar with, and to be easily accessible from the working place. A clear visual design such as the use of color codes facilitates the choice and location of materials. Material which is not needed in the short or medium term should be removed to reduce distractions.

Exchange of thoughtful reflections can be organized in larger groups or by the whole class. In this exchange situation, it is often necessary for the teacher to make suggestions in order to try out learning processes in the group. Questions about furniture are subordinate, although it is often helpful to set up the chairs in a circle or semi circle. This fosters communication between all members of the group and the exchange with the teacher, including active questions from students (Marx, Furher, & Hartig, 2000). For instructions or introductions, work in the whole group is usually suitable. If exchange and asking questions is not a central aspect of the lesson, but the focus is on silent listening instead, the chairs should be set up in rows or as in a theater (see Wannarka & Ruhl, 2008). In such situations the room acoustics have an essential role, especially for primary school students. Due to an auditory system yet to mature (Litovsky & Ashmead, 1997) they are strongly inhibited in their acoustic perception in rooms with long reverberation times, disadvantageous floor covering, and possibly additional noise from outside (Klatte, Hellbrück, Seidel, & Leistner, 2010). This sound problem not only influences the cognitive functions negatively, but is also an emotional strain.

The question of how much age- and gender-related preferences for group size should be taken into account to facilitate personal social interaction in design of the teaching process should be decided consciously, as this decision has an influence on the social forms primarily used in class. The seating arrangement should then be adapted accordingly.

A learning space needs to fulfill different requirements at the same time, and obviously compromises often need to be made in design. When there is enough space, it is possible to create multifunctional rooms that allow different kinds of social forms in the different areas of the room. But this is not always possible. It does not seem to be purposeful to try to find one arrangement for all circumstances. Evaluations in concrete teaching situations show that particular arrangements should be preferred for specific learning styles (see above).

Furthermore, neuroscientific findings show that a certain behavior that is acquired in a specific situation is also activated more frequently later on. Accordingly, the (semi) circle seating arrangement is not equally suited for active exchange and silent individual work. Therefore, measures need to be identified that are uncomplicated and can be used as rituals in order to signal the passage from one learning phase to the next. For example, in a semicircular seating arrangement the modification of the seating position at the desk (part of the students move to the "inner" side of the desk or to different desks, onto the floor, etc.) can already support the passage from exchange to individual or group work. Or exchange could always take place without desks (sitting in a circle), and group or individual work at the desk. A fixed relationship between situations and learning forms gives the students additional orientation. It relieves and is thus considerate of mental resources.

Spatial Design as a Process: An Example From Practice

Within the pilot project (House of Education 3 to 10) of the state Baden-Württemberg (Southwest of Germany), primary schools and kindergartens experiment at 33 different sites with new ways to cooperate, as they regularly (generally at least once a week) provide common educational settings for preschool and kindergarten children (from age 3 onward) and primary school children (up to 10 years of age). In the framework of our scientific support and evaluation of the project, we determine the topics practitioners will have to tackle in order to be able to implement the pilot project (Koslowski, 2010). Assessment of how often the teams of practitioners and caregivers deal with each topic enables us to measure the relative importance and relevance of each factor: Space issues represent, after personnel and time factors, the third most important element to be considered for a successful implementation in practice. As far as content is concerned, the topic "space" is divided into two aspects, one the planning and organization of space and the other the design of rooms. At the beginning of scientific support within the project, spatial design represented only about a quarter of the questions raised in the context, while the remaining three quarters were about spatial organization. However, within the first year, the percentage of design-related issues increased up to two thirds. How to use rooms differently, be they classrooms or not, was—and still is—quite high on the agenda: The questions are concerned with changes in arrangements, given that one has to start from a design related to whatever activity was previously conducted in the given space, and modify it in order to reach the desired or necessary design adapted to the requirements of the "House of Education" setting. This issue leads to a clear inconvenience, often described by the instructors as an important stress factor. In light of these results, it is obviously not a good idea to adopt a learning space design that requires important changes in the arrangement and heavy moving of furniture—even if it is only once a week. Due to the wide age range of children within the "House of Education 3 to 10" project, novel concepts, sometimes unheard of so far, are necessary to arrange learning spaces and to equip them with adequate material. As a consequence of this, it is not surprising that issues of spatial design can be dealt with only as a medium-term or even long-term goal. Moreover, it is striking to observe that for "House of Education" practitioners, spatial design conception actually follows the pedagogical process, be it at content-delivering level or at time-keeping level. Consequently a deep knowledge of course design and setting is necessary in order to implement the appropriate spatial design. These issues became obvious as new conceptions of both content and learning space were created and developed; this aspect can be only too easily forgotten for the issue of the design of rooms already in use. Because course arrangements are "already known anyway," they are not systematically listed in most priorities. There is a risk of both misevaluation and, as a consequence, a far from optimal room design (cf. Vincent, 1999).

CONCLUSION

There are several ways to support learning processes so that that they are close to natural forms of learning, while being mindful of resources. Therefore, when making decisions about method(s) in this framework, other aspects should be taken into account, such as class composition, age, mix of class levels, room size, social relations, and preferences and strengths of the teacher. The choice of methods is essential for the way seats are arranged in class, and how the room is organized: Multifunctional rooms with areas reserved for certain types of work are useful for open forms of self-organized learning. Rows focus the concentration on the teacher. Circles or semi circles usually foster communication, and interestingly also exchange with the teacher, and so on. A classroom design that does not correspond to the teaching method used primarily creates considerable strain for learners and teachers, and unnecessarily uses cognitive and physical resources. A nearly natural environment, clear structures in the room, and good acoustics liberate resources in learners and teachers that can then be used for a successful teaching–learning process.

In this article, general findings about learning, the underlying brain processes, and developmental aspects were linked to evaluation studies of learning environments. In future, more specific research in cooperation between neuroscientists, psychologists, and educational practitioners is necessary to examine the effects of the spatial organization of learning environments on the developing learning brain.

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