The present work was submitted to Lehr- und Forschungsgebiet Educational Technologies at DIPF

The Effects of Environment on Individual Learning

Bachelor Thesis

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Frankfurt, February 20, 2020

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I hereby declare that I have created this work completely on my own and used no other sources or tools than the ones listed.

Frankfurt, February 20, 2020 Full Name

Acknowledgments

My deepest gratitude goes to my friends and family for always supporting and motivating me in the past.

I would also like to thank Prof. Dr. Hendrik Drachsler for giving me the opportunity to research this interesting topic. I would like to express my gratitude to Mr. Ciordas-Hertel for guiding me through this project.

And finally, a big shout-out to all the students who participated in my study.

Abstract

The environment can have various effects on humans and human cognition. In order to support students in their studies, it is important to understand how the environment can affect their learning process. In a literature review, it was found that the environmental aspects noise, light, color, smell, space, air quality, temperature, and social presence can have both, positive and negative effects on humans in general and on individual learning, sometimes differing effects depending on the task type, and that there are ways to avoid negative effects and to take advantage of positive effects. Especially noise might be detrimental to learning, and therefore, a quiet environment might generally be the most important feature of a good learning environment. According to a small study, the Learning Environment Wizard, a website designed to help students in finding good learning environments, seems to have good usability. There are many more aspects to investigate, additional features that can be implemented on the website, as well as other technologies to support students in finding or creating good learning environments.

Zusammenfassung

Die Umwelt kann verschiedene Effekte auf Menschen und menschliche Kognition haben. Um Studierenden bei ihrem Lernen zu unterstützen, ist es wichtig, zu verstehen, wie die Umwelt ihren Lernprozess beeinflussen kann. In einer Literaturanalyse wurde herausgefunden, dass die Umweltaspekte Geräusche, Licht, Farbe, Geruch, Raum, Luftqualität, Temperatur und soziale Präsenz sowohl positive als auch negative Effekte auf Menschen im Allgemeinen und auf individuelles Lernen haben können, teilweise unterschiedliche Effekte abhängig von dem Aufgabentyp, und dass es Wege gibt, die negativen Effekte zu vermeiden und die positiven Effekte zu nutzen. Vor allem Geräusche könnten einen negativen Effekt aufs Lernen haben, und daher ist im Allgemeinen eine ruhige Umgebung möglicherweise die wichtigste Eigenschaft einer guten Lernumgebung. Der Learning Environment Wizard, eine Website, die entwickelt wurde, um Studierenden dabei zu helfen, gute Lernumgebungen zu finden, scheint einer kleinen Studie zufolge eine gute Usability zu haben. Es gibt viele weitere Aspekte zum Untersuchen, zusätzliche Funktionen, die auf der Website implementiert werden können, sowie andere Technologien, um Studierende dabei zu unterstützen, gute Lernumgebungen zu finden oder zu erschaffen.

Contents

1 Introduction

In recent years, the field of learning analytics has been working hard on finding ways to improve students' learning. After all, a situation in which students learn efficiently and become well-educated is not only the goal of teaching institutions but also more motivating for their students. Approaches include the development of early warning systems that determine whether a student might be at risk of failing a course and various feedback systems for teachers and students about their progress and participation (Ferguson 2012). However, these approaches do not take into account the effects that the environment can have on the student's learning success.

It can be easy to forget our environment since, naturally, we are surrounded by it at all times and, as a result, are accustomed to the numerous environmental changes we generally experience every day. For example, the temperature might change as we step out of a heated building into the cold, the CO_2 content in a room full of people might slowly increase due to respiration if no window is opened, a barking dog or talking people might walk past us in the park, and a room slowly becomes darker as the sun sets unless we turn on electric lights. However, it is important that we become aware of and understand how we and our cognition are affected by the environment: if the environment is unfit for learning, even the best learning program will be futile, and, as Branham (2004) said in the face of decreased attendance rates and increased drop-out rates due to badly maintained school buildings in need of repair, "[t]he best teachers, the best principals, and the best administrators have absolutely no value in improving education if children do not come to school" (p. 1113).

Therefore, the aim of this Bachelor thesis is to examine what the environmental properties of a good learning space are. For this purpose, the effects of the environment on human learning will be researched. Additionally, the effects of the environment on humans in general will be examined, as they might help explain some of the effects on learning and, thus, contribute to a better understanding of those effects. The recommendations for a good learning environment will be compiled in two frameworks, one for students who want to find good learning spaces, and one for higher teaching institutions that want to provide them. Further, a wizard based on the framework for students will be developed in order to help students find good learning environments in practice.

In short, the goal of this thesis is to answer the following research questions:

1. RQ01: How does the environment affect humans in general?
2. RQ02: How does the environment affect individual learning?
3. RQ03: Is there any relationship between the environment's effects on humans in general

and its effects on individual learning?

4. RQ04: What are the properties of a good learning environment?
5. RQ05: What can teaching institutions do in order to provide optimal learning environments for students?

The remaining part of the thesis is organized as follows: In the next chapter, I will provide a short overview over existing papers on this topic and work out areas which need more research. In the third chapter, various papers on the effects of the environment on humans in general and specifically on individual learning will be examined in order to answer questions RQ01 and RQ02. Question RQ03 will be discussed in the Discussion subchapter of the third chapter as well, in order to gain a better understanding of the environment's effects on cognition. Further, recommendations for two frameworks for college students and higher teaching institutions on optimal learning environments will be worked out based on the findings of the preceding literature review out in order to answer questions RQ04 and RQ05. In the third chapter, the implementation of the Learning Environment Wizard, a website designed to help college students in Frankfurt am Main, Germany find and evaluate learning environments, will be presented, after which the results of a small student survey on the wizard's usability will be analyzed and discussed in the fourth chapter. Finally, in the fifth chapter, we will take a look at how the Learning Environment Wizard might be improved and extended, what other possible ways of supporting students in regards to learning environments exist, and which areas might need further research.

2 Related Work

Environmental effects on individual learning have been researched in numerous studies, especially in the K-12 school context. Most papers investigate the environmental aspects noise, light, air quality, and temperature (Earthman 2004; Schneider 2002; Barrett et al. 2015; Spivack, Askay, and Rogelberg 2010; Lyons 2001). Sometimes other aspects such as building condition (Lyons 2001; Schneider 2002; Lackney 1999), portable classrooms (Lyons 2001), seating arrangements (Choi, Van Merriënboer, and Paas 2014), classroom equipment (Earthman 2004), and links to nature in classroom design (Barrett et al. 2015) are examined as well. Some papers even investigate aspects that might not be considered purely environmental in the physical sense, such as personalization (Barrett et al. 2015; Spivack, Askay, and Rogelberg 2010), e.g., regarding classroom furniture, or territoriality (Spivack, Askay, and Rogelberg 2010). Other environmental aspects, such as smell or social presence, are rarely examined.

Unfortunately, these papers lack investigations of environmental effects on adults. The majority of existing studies examine K-12 schools for children under the age of 18 years; however, the findings of studies on children might not be applicable to adults, since the environment might affect adults differently than children. Additionally, as mentioned above, some aspects are rarely examined and deserve closer investigation as they might be relevant for learning, especially social presence for collaborative learning. For these reasons, this Bachelor thesis aims to research the effects of the environment, including less often examined environmental aspects, on humans and individual learning with a special focus on adults. This is also necessary in order to ensure applicability of the frameworks for college students.

3 Literature Review

At all times, we are surrounded by our environment. It is not a far-fetched assumption that the environment has an effect on us. In this chapter, we will see that this intuitive belief is not only scientifically proven, but that there are also ways to quantify the environment's impact on humans – not only through measurement of subjective perception, but also by means of more objective measurements, such as test scores, measuring hormonal changes, e.g., in melatonin level, or physiological effects, e.g., changes in pulse rate.

In the main part of this chapter, I will examine and discuss various studies and literature reviews on the effects of the environment on individual learning, but also on humans in general in order to gain a general understanding of how we are influenced by our environment, as this knowledge may later help us better understand the environment's effects on individual learning. These findings will answer RQ01 and RQ02. Then I will use those findings to develop two frameworks as an answer to RQ04 and RQ05: one for college students on how they can find optimal learning environments, and one for higher teaching institutions on how they can provide good learning environments. The reason why these frameworks are aimed specifically at college is that the first framework will later be used to develop a corresponding wizard for college students and, as we will soon see, the environment can impact adults differently than children.

The first question we must ask in order to examine our environment in more detail is which aspects our environment consists of. In environmental psychology, the array of aspects viewed as having an impact on humans varies: Spivack, Askay, and Rogelberg (2010) write that "[e]nvironments can be defined based on their objective, hard and quantifiable physical properties, such as intensity of lighting, volume of background noise, and color of a room" (p. 38). In their literature review, Earthman and Lemasters (1996) examined the aspects school building age and maintenance, temperature, light, color, and noise and found them to impact student achievement, and Schneider (2002) comes to similar conclusions regarding spatial configurations, noise, heat, cold, light, and air quality. Similarly, Choi, Van Merriënboer, and Paas (2014) define the physical learning environment as "physical properties of a place where teaching and learning takes place", including

> "physical characteristics of learning materials or tools (e.g., texture, color, size, shape, weight, and sound), the physical attributes of the built environment (e.g., volume, density, lighting conditions, arrangement, and thermal conditions), natural spaces, and the physical presence of other people",

but also "sensory stimuli perceived by human senses" such as "vision, hearing, smell, taste, touch, temperature, and balance" (p. 229). Higgins et al. (2005), too, examined "basic physical variables", especially air quality, temperature, and noise, as well as lighting and color.

Generally, there seems to be wide agreement that the physical aspects noise, light, color, space, temperature, and air quality are environmental aspects, and thus they will be examined in this literature review. Choi, Van Merriënboer, and Paas (2014) seem to be some of the few researchers who also include sensory stimuli such as smell, taste and touch. As taste and touch are only relevant in specific activities such as food intake and actively touching something which are not typically done in a learning setting, they will not be included in this literature review. Smell, however, might be of more importance, especially when it comes to learning, as inhaling scented air might be an easy and passive way of increasing performance if smell is indeed found to impact learning. Of all papers mentioned above, the one by Choi, Van Merriënboer, and Paas (2014) is also the only one to include social presence. However, social presence and interaction might be an important aspect to examine in the context of learning, as collaborative learning is very common and might have varying benefits or disadvantages compared to individual learning. Thus, this aspect will be examined as well.

In short, the effects of the following environmental aspects will be examined:

- **Noise**: This aspect includes noise coming from within the currently occupied (class-)room as well as noise from outside the room.
- **Light**: This aspect includes daylight as well as electric light.
- **Color**: This aspect focuses on the wall color(s) of the currently occupied room, since the majority of found studies examine merely wall color.
- **Smell**: This aspect encompasses strong scents from essential oils, as all found studies examine the effects of essential oils.
- **Space**: The mere amount of space does not seem to impact individual learning (Earthman and Lemasters 1996) and many other papers examining "space" actually examine other physical properties of rooms, such as wall color and room acoustics which are examined in the aspects Color and Noise. One spatial aspect not defined through other environmental aspects, however, is crowdedness. Thus, this aspect will be defined as the crowdedness of a room.
- **Air Quality**: This aspect refers to indoor air quality, influenced by ventilation rates and the CO_2 content of the room.
- **Temperature**: This aspect is defined as the air temperature in the room, influenced by factors such as sun radiation or radiators.
- **Social Presence**: This aspect refers to social relationships and interaction with other people. Consequences of the mere presence of people, such as increased speech levels or crowdedness, are examined in seperate aspects such as Noise and Space.

3.1 Method

Suitable papers for the literature review were searched for using primarily Google Scholar, Researchgate, and ERIC. For the first search, keywords included *learning environment, physical learning spaces, physical environment, workplace,* and *environmental effects*. The main keywords for all searches were *effect* and one of the keywords *learning, cognitive performance,* *academic performance, cognitive tasks,* or *cognition* for the research of effects on cognition, or one of the keywords *humans, mood, behavior, physiology, health,* or *alertness* for the research of effects on humans in general. Additionally, one of the according environmental aspects was used, or a similar keyword: for noise, keywords included *noise, music, audio,* and *sound*; for light, keywords included *light, daylight, melatonin* and *6500K*; for color, keywords included *color* and either *room* or *wall*; for smell, keywords included *smell, scent, aroma*, and *essential oil*; for space, keywords included *space, room, design, crowdedness,* and *crowded*; for air quality, keywords included *air quality, ventilation rate,* and *CO2*; for temperature, keywords included *temperature, heat,* and *cold*; and for social presence, keywords included *social presence, presence of others, collaborative learning, loneliness, group learning, social interaction* and *social network*. The results were filtered according to title first, and then according to their abstract. Finally, more suitable papers were often found through the references of the initial results, if access could be obtained.

Studies on the effects of the environment on individual learning were included if they examined how certain realizations of environmental aspects improve or decrease cognitive task performance of individual humans, with the exception of studies on collaborative learning in which several people work together on a task. Studies on the effects of the environment on humans in general were included if they examined how certain realizations of environmental aspects influence human behavior, mood, or health. Additional criteria for choosing papers were (a) age, as very old studies might be outdated, so studies from 2000 or later were preferred over older studies; (b) credibility, e.g., sources were cited, appropriate statistical testing was conducted, and the number of participants was large; and (c) relevance, i.e., studies on adult college students were preferred over studies on K-12 students (aged 6-17 years) in order to ensure applicability of the framework for students. Studies on pre-K children (aged 0-5 years) were disregarded, as very young children are still developing and thus might react to the environment differently than adults; for instance, the lung keeps developing until a child is approximately 6 years old (Schwartz 2004) which could affect a child's sensitivity to indoor air pollutants; children's color preferences change while they mature and become adults (W. Daggett 2008; Terwogt and Hoeksma 1995); and generally, "[i]t is widely accepted that young learners are more sensitive to the impact of the physical learning environment than adults" (Choi, Van Merriënboer, and Paas 2014, p. 236). At least two studies per environmental aspect were examined, in order to ensure sound and well-balanced research. No more searches for literature were conducted after January 31, 2020.

Each subchapter starts by examining studies on the aspect's effects on humans, followed by a short summary. Then, each aspect will be discussed in the discussion subchapter (paragraph 3.10) in which possible relationships between general effects and effects on cognition are examined in order to answer RQ03, and recommendations for optimal learning environments are worked out. Finally, the two frameworks are presented, limitations are discussed, and a conclusion is drawn.

3.2 Noise

For students studying in crowded buildings such as universities, it can be difficult to avoid experiencing noise from other students. But should this circumstance be considered worrisome or does noise perhaps not affect humans?

3.2.1 Effects on Mood

A literature review by Kjellberg (1990) examined numerous effects of noise on humans. The findings were intended to be applicable especially for occupational noise exposure, i.e., exposure at a workplace, which is why mainly moderate noise levels were examined. Although findings were inconsistent, the authors conclude that "it is evident that the nonauditory effects of noise may be serious enough to warrant as much general attention in the occupational setting as has for some time been accorded in residential settings" (p. 29). The authors found that noise can have several effects on mood: it can cause irritation and annoyance, especially for those with hearing impairment, with annoyance increasing approximately at the same rate as the increase in subjective loudness of a sound. Generally, people do not get used to noise even after long exposure; in fact, they might even get more annoyed as time passes. Compared to mere loudness, however, it was found that "non-physical noise characteristics are of great importance" (p. 31), e.g., unexpected, uncontrollable noise as well as variability and sudden increases in noise level are deemed especially annoying and stressful. Szalma and Hancock (2011) share this view and found that schedule and type of noise are more important than intensity and duration. On the other hand, Kjellberg (1990) also found that such non-physical noise characteristics can make people less annoyed, e.g., if they understand why the noise is necessary and have a positive attitude towards the noise source. Further, Kjellberg (1990) found that loud noise can also ensure privacy by masking other sounds such as private conversations. No evidence of the current task or activity influencing the subjective experience of noise were found. The concept of individual noise sensitivity was seen skeptically: reliably measuring noise sensitivity seems problematic and its role in determining annoyance ratings is questionable.

3.2.2 Behavioral Response to Noise

The literature review by Kjellberg (1990) further notes that noise can elicit three kinds of immediate behavioral responses: an orienting reflex, a defensive reflex, or a startle reflex. Generally, humans react to noise with the so-called orienting reflex where one directs one's sense organs and attention to the noise source; physiological changes such as lowered blood pressure might take place as well. This reaction becomes less dominant if the noise is perceived as unimportant, especially for low-level and quickly repeated noise. If, however, the noise level is high, the immediate response is a defensive reflex which takes much longer to diminish, or – if the onset is sudden – even a startle reflex such as blinking which hardly ever diminishes. A more general behavioral effect of noise is that it might make people less helpful to each other, perhaps because they get distracted by the noise or because the noise irritates them.

3.2.3 Effects on Health

The previously mentioned literature review by Kjellberg (1990) examined the effects of noise on health as well. Noise might generally raise the arousal level, unless it is continuous or repetitive noise, in which case people might get sleepy. For resting people, noise has been shown to raise diastolic blood pressure; however, results on pulse rate and hormones like cortisol are less consistent. Generally, uncontrolled noise elicits stronger psychophysiological responses. Long-term effects of noise might be cardiovascular problems such as hypertension, whereas mental illnesses seem less likely; however, findings on long-term effects are inconsistent.

3.2.4 Negative Effects on Cognition

Kjellberg (1990) also found noise to affect cognitive performance. The possibility of negative behavioral effects of noise on performance are seen as an "undisputable fact" (p. 32) if the task involves auditory cues, perhaps even in non-auditory tasks, especially with intermittent and unpredictable noise. These effects manifest primarily as distraction – by environmental change, i.e., start and end of noise, but also by irrelevant speech, i.e., meaningful noise. Effects on workplace accident rates and productivity are not clear. It seems that simple reaction-time tasks, motor performance, sensory tasks and other simple tasks such as proofreading are unaffected by continuous noise, whereas other reaction-time tasks are affected and more errors are made even at moderate noise levels as time passes; vigilance tasks might be negatively affected even at low noise levels if the signal to be monitored is more complex. Noise might also "lead to a more superficial processing of text and, thus, to impaired comprehension" (p. 34), and it can impair the memorization process by causing a learner to semantically connect less words to each other, e.g., when learning lists. Verbal short-term memory is consistently affected by irrelevant speech, regardless of speech level and language. Generally, noise seems to lead "to an increased concentration of attentional resources on the aspects of the tasks deemed most important" (p. 34) so that only the most necessary items are learned. A critical level of noise where it starts to impact performance could not be determined due to dependence on many other variables.

A literature review by Szalma and Hancock (2011) which examined 242 studies comes to similar conclusions. It was found that there is little evidence that noise affects performance speed; however, noise "reduces performance accuracy and short-term/working memory performance" (p. 683), perhaps due to distraction or increased mental workload, e.g., through stress or annoyance, which is consistent with the findings of the previous literature review. Especially intermittent impact noise, i.e., relatively infrequent noise of short duration, was found to have a negative effect due to the startle and orienting response, which was also concluded by the other literature review. Further, negative effects on performance of cognitive tasks, psychomotor tasks and tasks requiring communication were found. Continuous music did not seem to have a negative impact on performance and there was little evidence for speed-accuracy tradeoffs on tasks.

A literature review by Reinten et al. (2017) examined 12 studies on the effects specifically of natural, typical office sounds such as typing, printing or walking sounds on task performance in an office setting. The results showed that, firstly, if speech intelligibility is important in the situation, processing and remembering the speech content is affected by noise. Secondly, if speech is considered a distractor, lowering the speech volume from 40 to at least 20 dB improves serial recall performance. The unit decibel (symbol: dB) measures the level of oscillating pressure of the vibrations that we perceive as sound; in short, it measures the sound level (Mehta, Zhu, and Cheema 2012). Thirdly, Reinten et al. (2017) found the effects of office noise to depend on the current task; for example, proofreading performance was worse in the reverberant condition while speed of typing was slower in the absorbent condition, with subjective assessment not always accurately reflecting objective performance. The study concludes that the effect of room acoustics on performance depends on the task, the sound source, the relation between those two, as well as personal factors. The authors note that "shielding yourself from any external stimuli might even be detrimental to work performance" because "speech from colleagues may also be directed at you" (p. 325).

Noise might especially have an impact on students with additional learning needs. An online questionnaire by Connolly et al. (2015) on 2588 11- to 16-year-old students' impressions of their school's acoustic environment revealed that learners with additional learning needs such as receiving learning support, having English as a second language, or having a hearing impairment felt more affected by their school's poor acoustics than students without additional learning needs, e.g., they could not hear the teacher as easily and the noise annoyed them more; especially those with multiple additional learning needs were significantly more affected by noise than students with just one or none additional learning need. However, these findings might not be applicable to adult students.

3.2.5 Positive Effects on Cognition

With so many studies finding negative effects of noise on cognition, it is perhaps surprising that noise can also have positive effects: a series of studies by Mehta, Zhu, and Cheema (2012) examined the effects of ambient noise, e.g., cafeteria noise and traffic sounds on creativity, and it was found that "a moderate (70 dB) versus low (50 dB) level of ambient noise enhances performance on creative tasks" (p. 784). The results indicate that the underlying mechanism consists in a moderate level of distraction through noise which "induces processing disfluency [difficulty], leading to abstract processing and thus to higher creativity" (p. 789). High levels of noise of 85 dB, however, reduce processing capacity and, as a result, decrease creativity. Mood and processing motivation had no impact on the results. Furthermore, although moderate levels of noise did initially increase physiological arousal, this arousal subsided over time, whereas "the high processing disfluency level induced by moderate noise appeared to persist over the course of the experiment" (p. 791), indicating that, firstly, increased arousal did not explain the observed effects, and secondly, that "processing disfluency, as opposed to arousal, drives this effect" (p. 791). These findings, despite the negative effects on cognition found by other studies, are not inconsistent with the previous studies, as they did not examine the effects on creativity, but on other aspects of cognition, such as vigilance, memorization, and text comprehension.

3.2.6 Effects on Introverts vs. Extroverts

Certain effects of noise on mood and cognition might depend on personality traits: A study by Standing, Lynn, and Moxness (2013) examined specifically the differences between introverts and extroverts regarding their reaction to noise. 60 undergraduate students were asked to perform tasks that measured aggressiveness and to fill out a questionnaire measuring anxiety in either a quiet or a loud condition with the noise source being white noise in both conditions. The results showed that state anxiety increased with noise in both, introverts and extroverts, whereas aggressiveness remained unchanged. The subjects were also asked to complete a reading comprehension task and assess their noise preference, and subjective activation as well as physiological arousal were measured. It was found that, although both groups performed equally well on the reading comprehension task in the quiet condition, introverts performed worse in the loud condition while extroverts stayed at the same level. The subjects' noise preference was unaffected by the noise level, but introverts disliked noise more than extroverts. Noise also increased the introverts' arousal level such as their pulse rate in the loud condition; however, their arousal level was not generally higher than the extroverts', as it was lower than theirs in the quiet condition. The extroverts' arousal level, on the other hand, seemed to decrease with noise. Generally, noise seems to negatively affect introverts' cognitive performance more than extroverts' performance.

3.2.7 Effects of Music

Some students might enjoy listening to music while studying. But does this practice have any adverse effects on the learning outcome? A study by Alley and Greene (2008) investigated the effects of vocal music, instrumental music and irrelevant speech on the cognitive performance of 60 college students, specifically their working memory. The subjects performed digit span tests under each of the following conditions at a for them comfortable noise level: silence, irrelevant speech, vocal music and an instrumental version of the vocal music. Two pop songs that were famous at the time were used. After the tests, they were asked to rate their familiarity with the songs and their perceived level of distraction. The results revealed that irrelevant speech and vocal music significantly decreased performance compared to silence, presumably due to their verbal content disrupting the phonological loop, as the other literature reviews found. The performance of subjects hearing instrumental music, however, was significantly better than the performance of subjects hearing vocal music and did not differ significantly from those working in silence. Familiarity with lyrics had, surprisingly, little impact on performance and perceived level of distraction, in the instrumental and the vocal version – it had been hypothesized that subjects would try to remember the lyrics and get distracted that way, but this was not the case. More importantly, subjects could not properly assess the sound's effect on their performance. It was concluded that instrumental music does not disrupt the phonological loop, while language, whether spoken or sung, does. This result is consistent with previous findings by Szalma and Hancock (2011) and Kjellberg (1990). However, subjects performed best in silence, and instrumental music "may be worse than silence for some people or under some condition" (p. 287).

3.2.8 Theories

The previously mentioned literature review by Szalma and Hancock (2011) on 242 studies mainly examined which one of three different theories best describe the effects of noise on humans: the arousal theory, according to which noise increases arousal regardless of noise type; the composite theory, according to which noise, regardless of noise type, affects human learning by masking the so-called phonological loop which is used to rehearse verbal information held in the working memory; and the maximum adaptability theory, according to which human performance is decreased through cognitive under- or overload, i.e., at high noise levels and especially speech, humans have to compensate the resulting overload by increasing effort which then decreases performance. Only mixed evidence was found for the arousal and composite theory. For example, speech decreased performance more than non-speech did, although both theories do not distinguish between noise type, and a shorter duration of noise was found to decrease performance more than long exposure – perhaps because you can get used to long exposure –, despite both theories claiming that long exposure would have worse effects. Most evidence was found for the maximum adaptability theory: for example, as predicted by the theory, intermittent speech of short duration negatively affected performance most of all, because this kind of noise uses information processing resources and a human is not able to adapt quickly enough to the noise due to its short duration; unlike claimed by the other two theories, the noise type matters, as the informational content of speech distinctly increases its ability to disrupt the phonological loop. Therefore, the maximum adaptability theory seems to best describe the effects of noise on cognitive performance.

3.2.9 Mitigating Negative Effects

An institutional way of mitigating negative effects of noise consists in adding sound absorbing material to rooms: the literature review by Reinten et al. (2017) mentioned earlier found that adding such sound absorbing material to a room can improve serial and free recall performance, auditory processing, memory, and comprehension of learning tasks. Furthermore, a study by Paulus and Matthews (1980) revealed that informing subjects on the negative mood effects they can expect to experience due to noise mitigates those effects (see paragraph 3.6.4).

3.2.10 Summary

The summarized effects of noise can be found in Table 3.1.

Further important points are:

- irrelevant speech (vocal music) and intermittent, unpredictable, uncontrollable noise most distracting
- type, schedule more relevant than intensity, duration

Type	Mood	Health	Cognition	Behavior
noise in general	annoyance, irritation, anxiety	increased arousal, increased diastolic blood pressure; cardiovascular diseases (long-term)	impaired text comprehension, impaired memory	less helpful to other people
intermittent, unpredictable, uncontrollable noise	*n. e. f.*	stronger psychophysiological response	memory accuracy especially decreased	*n. e. f.*
irrelevant speech, vocal music	*n. e. f.*	*n. e. f.*	short-term memory impaired	*n. e. f.*
instrumental music	*n. e. f.*	*n. e. f.*	short-term memory not impaired	*n. e. f.*
office sounds	*n. e. f.*	*n. e. f.*	proofreading, speech processing, memory affected	*n. e. f.*
moderate ambient noise	*n. e. f.*	*n. e. f.*	enhance creativity	*n. e. f.*
continuous noise	*n. e. f.*	increased sleepiness	unaffected if task simple	*n. e. f.*

Table 3.1: The summarized effects of noise on human mood, health, cognition, and behavior according to the reviewed papers. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of noise on the according human aspect were found in the literature review.

- maximum adabtability theory most fitting
- immediate response: orienting, defensive, or startle reflex
- little to no habituation except for continuous or repetitive, low-level noise
- introverts, children with additional learning needs especially affected by noise
- effects mitigated by education, sound absorbing material

3.3 Light

Two of the units used in this literature review to characterize certain physical properties of light are lux and kelvin. Lux described the level of illuminance of light (symbol: lx or lux) (Chellappa et al. 2011; Jewett et al. 1997). Correlated lamp color temperature, on the other hand, uses the unit kelvin (symbol: K), and indicates "the relative proportion of warm versus cool colours in a light source", so that, e.g., light with a correlated lamp color temperature of 6500 K is considered "cold light", whereas 2500 K light is considered "warm light" (Chellappa et al. 2011, pp. 1-2).

3.3.1 Effects on Circadian Rhythm

Light has been shown to influence the human circadian system: In a study by Jewett et al. (1997) on 43 young men, it was found that bright light with 10000 lx induces phase shifts in the human circadian system throughout the subjective day with no or just a very small dead zone of 1 to 2 hours of light insensitivity between phase advances, i.e., earlier bedtimes, and phase delays, i.e., later bedtimes. Phase shifts take place within just two to three days, also because of the absence of a dead zone, enabling humans to "rapidly achieve stable entrainment in response to exposure to environmental light stimuli" (p. R1808). The study's results "indicate that the human circadian pacemaker is sensitive to light at virtually all circadian phases, implying that the entire 24-h pattern of light exposure contributes to entrainment" (p. R1800). Further, it was found that "small-to-moderate phase advances (2–3 h in 3 days) can be achieved by exposing patients to bright light during the first 8 h of their habitual waking day" (p. R1808).

Specifically, short-wavelength light has an effect on the release of melatonin which is closely related to the circadian rhythm: in a study by Figueiro and Rea (2010), eleven 8th grade students aged 13-14 years wore orange glasses which removed short-wavelength light for five consecutive days from when they woke up until they came back from school in the afternoon. In the evening, several saliva samples were collected every 30 minutes while the students stayed in a dimply lit room without daylight, and the saliva samples' melatonin content was determined. The results showed that dim light melatonin onset (DLMO) was significantly delayed by about 30 minutes after those five days, indicating the importance of short-wavelength light exposure during the day "for aligning circadian phase to the rest-activity cycle required by attending school" (p. 93), i.e., for entrainment.

3.3.2 Effects of Relationship between Sleep-Wakefulness and Circadian Rhythm on Cognition

The implications of the previous study become clear when one looks at the consequences of delayed DLMO: if DLMO is delayed, i.e., if a student gets sleepier at a later time, he might go to bed later, meaning the student will get less sleep as wake-up times are usually fixed for students. This lack of sleep due to a non-synchronized relationship between sleep-wakefulness and the circadian rhythm can then negatively impact scholastic performance, as shown in a study by Wolfson and Carskadon (1998): 3120 high school students filled out surveys on their sleep habits. It was revealed that there was a close relationship between the amount of sleep a student got and their grades. Over the ages 13 to 19 years, students had increasingly later bedtimes while rise times stayed fixed, so that students got 40-50 minutes less sleep over that period. Students who usually got C's, D's and F's got about 25 minutes less sleep and went to bed on average 40 minutes later than A and B students. Additionally, students getting less than 6 hours and 45 minutes of sleep and/or with more than 120 minutes weekend bedtime delay had significantly more daytime sleepiness, a more depressive mood and sleep/wake behavior problems than those sleeping longer than 8 hours and 15 minutes with less than 60 minutes weekend bedtime delay.

Similar effects can be seen in adults as well: a study by Wright et al. (2006) tested 17 healthy adults in a laboratory setting without time cues such as clocks while maintaining a synchronized relationship between sleep-wakefulness and circadian time in one half of subjects, and a non-synchronized relationship in the other half for one month. After one month, it was found that subjects in the non-synchronized group had higher melatonin levels and a lower body temperature – important markers of the biological night – during scheduled wakefulness, and more wakefulness after sleep onset in the second half of sleep compared to the synchronized group. Cognitive performance on tasks – requiring working and long-term memory, mathematical skills and speed of processing – improved in that timeframe in the synchronized group, "whereas learning was significantly impaired in the nonsynchronized group" (p. 508). The study concludes that "proper alignment between sleep–wakefulness and internal circadian time is crucial for enhancement of cognitive performance" (p. 508).

3.3.3 Direct Effects on Cognition

Light can have immediate positive effects on adults as well: in a study by Chellappa et al. (2011), 16 young healthy adults spent two hours in the evening after a period of dim light and darkness in one of three different conditions under light with a temperature of either 6500 K, 3000 K, or 2500 K, all conditions with an illuminance of 40 lx. Afterwards, they spent another hour in dim light before they went to sleep. During each of those phases, subjects filled out questionnaires on their well-being, tiredness, concentration, and the light, while regular saliva samples were collected to assess melatonin. They also performed various cognitive tasks of sustained attention and higher order executive functioning of the brain. The study found that subjects under 6500 K light, compared to the other two conditions, had a significantly greater melatonin suppression, starting at about 90 minutes of light exposure and lasting throughout the following dim-light phase, and that these "lower levels of salivary melatonin led to faster reaction times" (p. 8) in sustained attention tasks, but not in executive functioning tasks. These subjects also experienced enhanced alertness, increased well-being after about 30 minutes of exposure, and increased visual comfort. Mental effort, however, did not differ significantly between the three conditions.

Similar effects have been found on the cognitive performance of children: a study by Mott et al. (2012) on 84 grade 3 children aged 7-8 years found that, in classrooms with minimal daylight, different kinds of electric light can have an impact on students' reading comprehension scores. For one year, one half of the students practiced reading comprehension in light with 1000 lx and 6500 K, while the other half practiced in light with 500 lx and 3500 K. The first group of students improved at a significantly higher rate in reading comprehension than the group with poorer lighting. However, there was no significant effect on motivation and concentration.

3.3.4 Effect on Behavior

A study on 72 undergraduate students by Baron, Rea, and Daniels (1992) examined human decision-making behavior under four different lighting conditions. The conditions had two levels of illuminance – either 150 or 1500 lx – paired with either warm or cool white light. Among other tasks, students had to reach a decision, choosing between compromise, accommodation, competition, avoidance, and collaboration, regarding the written presentation of an interpersonal hypothetical conflict. The results showed that "[s]ubjects reported significantly stronger tendencies to resolve interpersonal conflicts through collaboration, but weaker tendencies to resolve them through avoidance, in the warm-white than in the cool-white condition" (p. 20), especially if they were additionally in a low-illuminance condition.

3.3.5 Effects of Daylight

In a much cited report on the effects of daylight by Heschong (1999), examination of test scores of 21000 students from three schools revealed that, in one of those schools, "students with the most daylighting in their classrooms progressed 20% faster on math tests and 26% on reading tests in one year than those with the least" (p. 2) and that "students in classrooms with the largest window areas were found to progress 15% faster in math and 23% faster in reading than those with the least" (pp. 2-3), and in the other two schools, "[s]tudents in classrooms with the most daylighting were found to have 7% to 18% higher scores than those in rooms with the least" (p. 3), despite different curricula, teaching styles and climates. The conclusions are believed to be transferable to other buildings such as offices. These positive effects might be attributed to improved visibility due to higher illumination levels or improved light quality, specifically: better distribution of light, especially vertically; better color rendition making colors look more vivid and true; absence of flicker which can lead to headache and eye strain; and sparkle or highlights on three-dimensional objects making understanding them three-dimensionally easier, more memorable or more lively. Other possible reasons for the positive effects of daylight include improved mood, behavior, and health, for example by increasing vitamin D levels, regulating the circadian rhythm, and increasing alertness through melatonin suppression.

Boyce, Hunter, and Howlett (2003) who examined not only schools but also offices, hospitals, and retail stores comes to similar conclusions regarding daylight. Besides being psychologically desired and contributing to entrainment, daylight is said to maximize visual performance through excellent color rendering as long as it does not cause visual discomfort through glare or distraction; however, the same is said to apply to electric lighting. How daylight impacts a person's mood depends largely on personal preferences and expectations, and its effect on performance is likely irrelevant compared to other influences, "unless the lighting is really uncomfortable" (p. 3). Regarding health, "[e]xposure to daylight can have both positive and negative effects" (p. 3). Positive effects include increased vitamin D production and less eye strain, whereas negative effects include tissue damage and increased eye strain, depending on the light.

3.3.6 Summary

The summarized effects of light can be found in Table 3.2.

Type	**Mood**	**Health**	**Cognition**	**Behavior**
10000 lx	*n. e. f.*	induce phase shifts in circadian system	*n. e. f.*	*n. e. f.*
6500 K/short-wavelength light	increased alertness, well-being, visual comfort	DLMO delayed	improved reading comprehension (in children), shorter reaction times in sustained attention tasks	*n. e. f.*
non-synchronized relationship between sleep-wakefulness and circadian rhythm	more depressive mood and sleepiness (in children)	markers of biological night during scheduled day and vice versa	decreased academic performance (in children), memory, reaction times, mathematical skills impaired	sleep/wake behavior problems
daylight	improved, increased alertness, visual discomfort through glare	melatonin regulation, entrainment, vitamin D production, tissue damage, eye strain	increased performance in reading and math (in children), increased visual performance	*n. e. f.*
warm light	*n. e. f.*	*n. e. f.*	*n. e. f.*	increased tendency to resolve conflicts through collaboration

Table 3.2: The summarized effects of light on human mood, health, cognition, and behavior according to the reviewed papers. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of light on the according human aspect were found in the literature review.

Further important points are:

- glare by artificial and daylight distracting
- effects of daylight on mood dependent on personal views
- flicker should be avoided

3.4 Color

What is color? The perception of color starts with light being reflected off of objects and entering the eye where it is converted to electrical impulses sent to the hypothalamus for interpretation; the hypothalamus manages the body's temperature, appetite, sleeping and other behaviors (Kurt and Osueke 2014). Considering these important functions of the hypothalamus, it is conceivable that color can impact one's mood or behavior. But is this view supported by empirical evidence?

3.4.1 Effects on Mood

Saturated colors, especially saturated yellow to which the eye is most sensitive, can cause psychological stress (W. Daggett 2008). A study by Kutchma (2003) examined this effect in more detail for the colors red and green in comparison to white. 30 undergraduate students were asked to wait in either a red, green, or white room for five minutes before they completed a questionnaire asking about occurrences of stress in the previous week. This procedure was repeated for the other two offices in random sequences with 5 minute breaks between rooms. The results revealed significantly higher stress scores of subjects in the red office compared to the white one. In a similar study, Kwallek et al. (2005) additionally found that subjects in the white office found the color less distracting, were more alert, were more satisfied with their perceived performance, and felt that the color helped their performance more than subjects in the red office. Kutchma (2003) found gender differences as well: female subjects had significantly higher stress scores in the red and green office compared to males, indicating that "males may not be as sensitive to color stimuli compared to females" (p. 8).

A study by Kwallek et al. (1996) came to slightly different conclusions than the first study by Kutchma (2003) regarding the effects of color saturation on gender: 675 adult subjects worked in nine monochromatic offices colored red, green, white, orange, yellow, blue, beige, purple, or gray with identical lighting for about 45 minutes. Before the subjects entered the office, and after they had completed their work, they filled out a questionnaire measuring six mood states. While higher-saturated office colors were associated with higher vigor scores for both genders, it was found that females reported more depression, confusion, and anger in low-saturated offices painted white, gray, and beige, whereas males reported these moods more often in high-saturated offices such as the blue, green, or red one. Though depression, confusion, and anger are not necessarily the same as stress which was measured in the previous study, it could be expected that these negative emotions occur in the same environment for the same gender, but this does not seem to be the case. The previous study, however, had very few subjects compared to the current one, and thus might be less meaningful.

3.4.2 Effects on Health

Different colors can have different effects on the body, e.g., red might raises blood pressure and pulse rate and increase respiration; blue, on the other hand, might have a calming effect on heart rate and respiratory system and lower body temperature; while green is seen as the most restful color for the eye (Gaines and Curry 2011). Saturated colors in particular might cause visual fatigue resulting in physical exhaustion (W. Daggett 2008).

3.4.3 Effects on Visual Perception

Color can also influence visual perception of rooms: in a study by Kwallek (1996), 124 undergraduate students stayed in a red, green, or white office before they filled out questionnaires on color perception and preferences in a neutral room. This procedure was then repeated for the other offices. White offices were viewed as most spacious compared to the other offices.

3.4.4 Screening Ability

Does color affect all humans to the same degree? A study by Kwallek et al. (2005) examined the impact of humans' screening ability, i.e., the ability to screen out irrelevant environmental stimuli such as color. It was hypothesized that color would have less of an effect on high screeners, i.e., people who "can efficiently decrease the contextual complexity and variability, leading to less arousal response to the environment" (p. 475), compared to low screeners. 90 subjects worked for four days for 8 hours a day in either a red, white, or a blue-green office and then completed a questionnaire on perceived performance and job satisfaction. The results revealed significant differences between high and low screeners: high screeners enjoyed working indoors more, reported being happier and less negative, were less anxious, felt that time passed more quickly, were more interested in their tasks, and felt that color hindered their performance less than low screeners. However, these differences disappeared after controlling for the subjects' neuroticism-stability score, indicating that not the screening ability but the neuroticism-stability score might be the predominant factor.

3.4.5 Effects on Cognition

In a literature review, Gaines and Curry (2011) found evidence of color impacting cognitive performance in children; especially those with disabilities were found to be sensitive to color in the classroom. W. Daggett (2008), too, found that especially saturated colors can cause errors and decrease performance as a result of visual fatigue.

Color can influence cognitive performance of adults as well: The study by Kwallek et al. (1996) (see paragraph 3.4.1) with 675 adult subjects proofreading in nine monochromatic offices found that, surprisingly, subjects made significantly more errors in the white office compared to the blue and red offices, even though the white office was rated the least distracting and most preferred. Generally, more errors were made in lighter offices painted beige, gray, yellow, or white, than in darker offices. Purple and yellow were rated most distracting, and purple and orange were the most unpopular colors. The finding that subjects were not able to correctly assess which color enhances their cognitive performance is supported by Mehta and Zhu (2009). Kwallek and Lewis (1990) come to similar conclusions regarding white offices: this color might decrease efficiency compared to red and green walls.

Although the color aspect was originally defined as wall color due to the majority of studies examining merely the effects of wall color, one study investigated the effects of background screen color of computers: Mehta and Zhu (2009) measured the effect of blue and red backgrounds on different types of cognitive tasks in a series of studies. It was found that "red (versus blue) can activate an avoidance (versus approach) motivation and subsequently can enhance performance on detail-oriented (versus creative) cognitive tasks" (p. 1228) and that mood had no impact on this effect. Detail-oriented tasks include memorization and understanding new material, whereas creative tasks include brainstorming and designing items.

3.4.6 Choice of Color

According to Engelbrecht (2003), a color scheme should "[s]upport the function of the building, and the tasks that are carried out in it" (p. 4) and "[c]reate positive emotional and physiological effects" (p. 4). However, Gaines and Curry (2011) write that "[f]indings are inconsistent in determining the optimal color choices in learning environments" (p. 49). As mentioned above, Kwallek et al. (1996) found that, even though the color of the white office was rated least distracting and was the most popular one, most errors were made in the white office, indicating that personal preference might not be a reliable indicator of adequacy. These findings are supported by the study by Kwallek (1996) (see paragraph 3.4.3). Interestingly, in this study, the subjects' top three colors deemed appropriate for an office – white, beige, gray – differ from their top three favorite colors – blue, green, red –, indicating that, although subjects prefer unsuitable office colors like white, this preference is not based on their favorite color in general. The least preferred and most distracting colors seem to be purple, yellow, orange, and red (Kwallek et al. 1996; Kwallek 1996).

The most agreed upon principle seems to be the one to "[a]void over stimulation and understimulation" (Engelbrecht 2003, p. 4). This view is supported by Gaines and Curry (2011) who found that excessive use of colors can lead to a stressful learning environment, whereas "colorless interior spaces can be stressful and nonproductive" (p. 54) as well. Generally, the authors call for balance in regards to color choice; recommendations include avoidance of strong or primary colors, warm neutral colors such as tan for the classroom's foundation, and a medium hue colored wall in the same color range that students see when they look up from their work.

3.4.7 Summary

The summarized effects of color can be found in Table 3.3.

Type	Mood	Health	Cognition
red	stress, decreased alertness, less job satisfaction	increased blood pressure, pulse rate, respiration	increased performance on detail-oriented tasks
blue	*n. e. f.*	calming effect on heart and respiration, decreased body temperature	increased performance on creativity tasks
white	increased alertness, more job satisfaction	*n. e. f.*	more proofreading errors, decreased efficiency
saturated colors	increased stress, vigor; females stressed in high-saturated offices, but more depression, confusion, anger in low-saturated offices	visual fatigue	more errors (in children)

Table 3.3: The summarized effects of color on human mood, health, and cognition according to the reviewed papers. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of color on the according human aspect were found in the literature review.

Further important points are:

- white probably unsuitable for offices, but most preferred and least distracting
- balance most recommended
- least preferred, most distracting: purple, yellow, orange, red
- effects of color saturation on gender inconsistent
- effects of screening ability probably due to neuroticism-stability score
- impact on perception of spaciousness (white most spacious)

3.5 Smell

Though often overlooked, as could be seen in the introduction to this chapter, the importance of the ability to smell to human well-being becomes clear when people who have recently lost this ability say that their emotional life has become "less eventful and grayer in tone" as a result and that they miss the "sudden appearance of their most vivid memories" (Köster 2002, p. 30). But do certain scents impact humans differently than others?

3.5.1 Effects on Mood

A study by Ilmberger et al. (2001) with 60-90 participants per session tried to answer this question by examining the effects of inhaled peppermint, jasmine and ylang-ylang essential oils as well as 1,8-cineole in two different dosages and menthol on alertness, defined as speed of information processing. Participants inhaled water in the first trial and a scent in the second trial, rated the odor's pleasantness and performed simple reaction time tasks for about 25 minutes. The control groups inhaled water in both trials. Though the study found no significant differences between control and experimental groups, the group receiving 1,8-cineole had shorter reaction times in the second trial compared to the first one, just failing to reach statistical significance, whereas all other groups had longer reaction times. Control groups had much shorter motor times in the second trial compared to the first one, whereas all other groups had longer or just slightly shorter motor times, perhaps due to distraction by the strong scents. With the exception of ylang-ylang which was rated significantly less pleasant than water, all other scents were rated more positive, intense and stimulatory than water. High dosage 1,8-cineole was rated significantly more relaxing compared to the first trial. Despite few differences in performance, it is noted that there were "complex correlations between subjective evaluations of substances and objective performance [within the groups], indicating that effects of essentials [sic] oils or their components on basic forms of attentional behavior are mainly psychological" (p. 239). For example, the more pleasant subjects rated water in the first trial, the more negative the motor time differences were in the ylang-ylang group; and the less stimulatory jasmine was rated, the slower motor times were in the second trial compared to the first one, which implies that subjects might have been influenced by their personal views of the scent.

In contrast, a study by Moss et al. (2003) which examined the effects of lavender and rosemary essential oil found several significant differences in alertness between groups. 144 healthy adults were randomly assigned to one of three conditions where they performed cognitive tests and filled out questionnaires measuring their mood before and after the cognitive tests in either an unscented cubicle or a cubicle with lavender or rosemary scent, being exposed to the scent for about 25 minutes as in the previous study. There were no differences in the pre-test on mood. After the cognitive tests, however, the control and lavender groups were "significantly less alert than the rosemary condition" (p. 16). Also, the control group was "significantly less content than both rosemary and lavender conditions" (p. 16). The study concludes that essential oils are indeed "capable of elevating mood, or at least maintaining good mood" (p. 33). However, there were no significant differences in calmness.

3.5.2 Effects on Cognition

The previously mentioned study by Moss et al. (2003) also found significant effects of essential oils on cognitive performance. The cognitive tests of this study examined the factors quality of memory, speed of memory, speed of attention, and accuracy of attention. The results revealed that "lavender produced a significant decrement in performance of working memory, and impaired reaction times for both memory and attention based tasks compared to controls" (p. 16), whereas "rosemary produced a significant enhancement of performance for overall quality of memory and secondary memory factors, but also produced an impairment of speed of memory compared to controls" (p. 16), concluding that these essential oils can "produce objective effects on cognitive performance" (p. 16).

A study by Akpinar (2005) found similar positive effects of certain scents on cognitive performance as well. 58 grade 4 students, divided into two groups which showed no significant differences regarding average grades and average success on cognitive tests at the beginning of the study, received English lessons in either a neutral classroom or a lemon scented classroom for two months. Cognitive assessments after that timeframe showed that lemon essential oil significantly increased the students' attention levels, enhanced their memory, and had positive effects on their cognitive test scores.

3.5.3 Summary

The summarized effects of smell can be found in Table 3.4.

Type	**Mood**	**Cognition**
lavender	increased contentedness	impaired working memory, longer reaction times
rosemary	increased alertness and contentedness	improved memory, impaired speed of memory
lemon	increased alertness (in children)	improved memory and cognitive performance (in children)

Table 3.4: The summarized effects of smell on human mood and cognition according to the reviewed papers. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of smell on the according human aspect were found in the literature review.

Further important points are:

- effects on mood inconsistent
- effects probably dependent on personal views of scents
- strong scents potentially distracting

3.6 Space

There are many negative effects of crowdedness, for example, airborne diseases can spread easily (Seino et al. 2005) and mass panics can occur, leading to physical injuries or even death (Illiyas et al. 2013). But what other effects can crowding have on humans?

3.6.1 Crowding Stress

In a study by Ulrich et al. (2018) on psychiatric wards designed to reduce aggressiveness of its patients, it is said that there is "much evidence that crowding stress and related aggression are linked to inadequacies in the physical environment that constrain the ability of persons to seek privacy, regulate their relationships with others, and avoid stressors such as noise and arguments" (p. 54). The authors distinguish between spatial density, describing the amount of space per person in a room or building, and social density, referring to the amount of persons per room in a building, noting that the latter is "the most consistently important variable for predicting crowding stress and aggressive behavior", whereas spatial density is "relatively unimportant unless space per person becomes constricted" (p. 54). This is concluded because "[c]onsiderable research on apartments and correctional facilities has shown that [social density] reliably correlates with higher crowding stress, reduced privacy, more aggressive behavior, illness complaints, and social withdrawal" (p. 56), even after controlling for spatial density. In psychiatric wards, especially corridors can trigger aggressiveness in patients due to perceived personal space intrusions.

3.6.2 Effects on Mood

Though these extreme findings of studies on mentally ill people do not necessarily reflect the effects that crowding can have on a healthy person, there is evidence that crowding can impact healthy adults as well: In a study by Epstein, Woolfolk, and Lehrer (1981), for example, 20 college students' behavior in uncrowded and crowded environments was observed. Once a week for three weeks, they were randomly sent for 20 minutes to either a very large room with an unknown group of helpers disguised as other subjects, or a very small room where physical contact with the helpers could not be avoided. The subject's heart rate, finger pulse volume, and blood pressure was measured before and while the subject was in the room, and afterwards the subject filled out a mood questionnaire. The helpers were told to avoid conversation and eye contact, but they were asked to inconspicuously observe the subject's behavior. The results revealed that crowded subjects were more tense and uncomfortable, e.g., they leaned into the corner more and looked more often at the ceiling, and as time passed, they made more nervous hand gestures. They were also more annoyed, and reported more negative mood than uncrowded subjects. No evidence for habituation to crowding was found.

If crowding had measurable effects on humans after just 20 minutes, it is conceivable that people living in crowded spaces over a long time may experience negative effects as well. This is indeed the case, as demonstrated in a study by Karlin, Rosen, and Epstein (1979): 63 college freshmen lived in groups of two or three students in rooms designed for only two people for 6 to 12 months; after that time period, all students lived in groups of just two students. Two years later, they participated in a follow-up study. It was found that, unlike doubled students, tripled students had a greater desire to change roommates in their freshman year than in the following years and felt more strongly that their roommates and their living condition had contributed to the unpleasantness of college life. Interestingly, tripled, but not doubled students liked college more and were less disappointed if their childhood household had been crowded as well. The authors conclude that

> "college dorm rooms are settings in which students have goals involving studying, relaxation, and positive social interaction. Tripling, to some extent, blocked these goals by creating unwanted exposure to chronically high levels of interaction. This was unpleasant, stressful, and created disappointment with college life." (p. 394)

3.6.3 Effects on Cognition

The previously mentioned study by Karlin, Rosen, and Epstein (1979) also revealed that crowding had negative effects on the students' academic performance: in their freshman year, tripled students, but not doubled students, had significantly lower grade point averages than in the following two years. Although tripled students liked college more if their childhood household had been crowded as mentioned earlier, their childhood experiences had no effect on their grades. The self-reports of the students in their freshmen year were very similar to their reports in the follow-up study, indicating that students did not forget their freshman experiences; but fortunately, crowding did not seem to have any negative long-term effects, as all students performed equally well academically and were just as satisfied with college after their freshman year. The authors write that "[c]ompeting activities in [the students'] rooms and the inability to control their environment also contributed to decreased academic performance" (p. 394). They hypothesize, however, that students might have experienced less negative effects of crowding if they had voluntarily chosen to be tripled, for example for financial reasons.

3.6.4 Mitigating Negative Effects

Besides voluntarily choosing to be crowded, another way of mitigating the harmful effects of crowding might consist in educating humans on the mood changes that they might experience in a crowded condition, as was found in a study by Paulus and Matthews (1980): 206 subjects performed a complex maze task in groups of four subjects in a noisy, crowded room, with a control group working in a quiet, uncrowded room. The noise included music, talking and traffic noise. Experimental groups were told that any anxiety or discomfort they might experience would most likely be due to either crowding, noise, or both, crowding and noise. One experimental group received no such information. Half of all groups were given a questionnaire on perceived crowding and mood before and after they completed the maze task; filling out the questionnaire did not influence their performance on the task. The results showed that those groups who were given either crowding or noise as a reason for possible negative feelings performed just as well as the control group and better than the groups who received either no additional information or crowding as well as noise as reasons for possible negative feelings. The authors conclude that "any reasonable information about the specific source of arousal in a crowded setting (whether the source is social or nonsocial) will reduce the negative impact of being crowded" (p. 3), perhaps due to subjects feeling more in control and being able to better cope with the anticipated negative effects of crowding or noise, whereas receiving both, crowding and noise as reasons might "maintain the subject's uncertainty or feelings of lack of control" (p. 10) and, thus, lead to decreased performance.

Epstein, Woolfolk, and Lehrer (1981) who in their study (see paragraph 3.6.2) found that crowded subjects had higher levels of physiological arousal, i.e., higher systolic blood pressure, also note that eye-closing was associated with significantly lower levels of anxiety and that this finding supports the theory that "arousal experienced by crowded subjects is due to an overabundance of unwanted sensory stimulation" (p. 10).

3.6.5 Summary

The summarized effects of space can be found in Table 3.5.

Type	Mood	Health	Cognition	Behavior
short-term	increased annoyance, tenseness, uncomfortableness, and negative mood	increased physiological arousal; risk airborne diseases and mass panics	decreased performance in combination with noise	aggressiveness (in mentally ill people)
long-term	crowding stress	greater desire to change roommates	decreased academic performance	*n. e. f.*

Table 3.5: The summarized effects of space on human mood, health, cognition, and behavior according to the reviewed papers. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of space on the according human aspect were found in the literature review.

Further important points are:

- social density more relevant than spatial density
- negative effects mitigated by education and eye-closing
- no evidence of habituation to short-term crowdedness
- no negative long-term effects on mood and academic performance after long-term crowdedness
- perception of long-term crowdedness, but not academic performance influenced by childhood crowdedness

3.7 Air Quality

Lyons (2001) writes that "[f]aulty classroom temperature and air circulation are two of the worst problems in schools today" (p. 2). Poor indoor air quality starting at CO_2 levels of 1000 ppm (1 part per million = 1/1.000.000 = 0.0001%) are assumed to cause the so-called Sick Building Syndrome (SBS), symptoms of which include "irritated eyes, nose and throat, upper respiratory infections, nausea, dizziness, headaches and fatigue, or sleepiness" (Schneider 2002, p. 1). But is this view supported by empirical studies? And is cognitive performance affected by poor indoor air quality as well?

3.7.1 Effects on Health

A literature review by Sundell et al. (2011) examined 27 peer-reviewed papers on ventilation rates in offices, schools, and homes, and concluded that the results are generally consistent: "Higher ventilation rates in offices, up to about 25 l/s per person, are associated with reduced prevalence of sick building syndrome (SBS) symptoms" (p. 191), whereas "inflammation, respiratory infections, asthma symptoms and short-term sick leave [seem to] increase with lower ventilation rates" (p. 191), though some panel members of the literature review found the evidence to be merely suggestive. The cause might be outdoor pollutants or dirty filters in the ventilation system. However, according to the authors, the exact relationship between ventilation rates and SBS symptoms remains unclear.

3.7.2 Effects on Cognition

Cognitive performance of adults can be affected by poor ventilation as well if it leads to higher indoor CO_2 levels: A study by Satish et al. (2012) examined the effects of ventilation rates on 22 adults who were exposed to three different CO_2 levels of 600, 1000 and 2500 ppm for 2.5 hours per level in an office-like chamber, while ventilation rate, temperature of 23℃, and relative humidity remained constant. After about one hour in each condition, participants completed tests measuring their decision-making performance, i.e., "complex human behaviors required for effectiveness in many workplace settings" (p. 1673). The results showed that performance was significantly decreased in six out of nine performance scales at 1000 ppm compared to 600 ppm, and even more so at 2500 ppm in seven scales so that percentile ranks for five of those scales "decreased to levels associated with marginal or dysfunctional performance" (p. 1674). For these scales, compared to 600 ppm, scores at 1000 ppm were 11-23% lower and scores at 2500 ppm were 44-94% lower. Compared to 1000 ppm, scores at 2500 ppm were 35-93% lower. For the aspect "information search", scores were similar in all conditions. For the aspect "focused activity", scores at 600 and 1000 ppm were similar, but significantly higher at 2500 ppm; it is hypothesized that "high levels of focus under nonemergency conditions may indicate 'overconcentration' [quotation marks changed]" (p. 1675), meaning that subjects might have been highly focused on details "at the expense of the big picture" (p. 1675). The authors stress that "[t]here is strong evidence that in schools, CO2 concentrations are frequently near or above the levels associated in this study with significant reductions in decision-making performance" (p. 1675) and that they "cannot rule out impacts on learning" (p. 1675). The authors conclude that the "[d]irect adverse effects of CO2 on human performance [...] may limit energy-saving reductions in outdoor air ventilation per person in buildings" (p. 1671), even if other indoor pollutants are controlled.

3.7.3 Effects on Cognition in Children

Just like adults, children also experience decreased cognitive performance as a consequence of poor ventilation, as found in a study by Haverinen-Shaughnessy and Shaughnessy (2015). The study was conducted on 3109 grade-5 students from 70 different schools and found "statistically significant association between ventilation rates and mathematics scores" (p. 1), especially when six outliers were filtered, and that "the association remained significant when prior year test scores were included in the model, resulting in less unexplained variability" (p. 1). The students' average score was increased by up to 0.5% for each liter per second per person increase in ventilation rate within 0.9 to 7.1 l/s per person. However, no evidence for a relationship between ventilation rates and absence due to illness was found.

A similar study by Wargocki et al. (2005) on 10-year-old students found that, even though students were in their classrooms for only 2.3 h/day on average, increased outdoor air supply rates, increased from 5.2 to 9.6 liters/s per person, in combination with decreased temperature, reduced from an average temperature of 23.6℃ to 20℃, significantly increased the students' work rate at a constant error rate on five out of eight cognitive tasks by 9.5 to 28%, depending on the task.

3.7.4 Summary

The summarized effects of air quality can be found in Table 3.6.

Type	**Health**	**Cognition**
low ventilation rates	increased occurrence of SBS symptoms	decreased mathematics scores (in children)
high CO_2 levels	*n. e. f.*	decreased decision-making performance

Table 3.6: The summarized effects of air quality on human health and cognition according to the reviewed papers. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of air quality on the according human aspect were found in the literature review.

3.8 Temperature

The study by Haverinen-Shaughnessy and Shaughnessy (2015) (see paragraph 3.7.3) also examined the effects of temperature on children's cognitive performance: It was found that their mathematics scores increased slightly more than 0.5% for each 1℃ decrease in temperature within 20 to 25℃. But does temperature affect adults as well?

3.8.1 Effects of Heat on Mood

A study by Lan et al. (2011) assessed the effects of thermal discomfort on 12 college students in an office setting. The subjects performed neurobehavioral tests such as grammatical reasoning, visual learning, memory, and number calculation, as well as office work such as text typing and addition at either 22℃ or 30℃ while wearing clothing suitable for 22℃. Noise, the ventilation rate, and humidity were kept constant. Physiological measurements and subjective assessments were used to determine the impact of temperature on the subjects. The results revealed that subjects in the hot condition had a more negative mood and were less willing to exert effort.

3.8.2 Effects of Heat on Health

The study by Lan et al. (2011) (see paragraph 3.8.1) also found that heat has numerous effects on human health: physiological effects included increased heart rate, increased respiratory ventilation rate and decreased arterial oxygen saturation as well as significantly reduced tear film quality on the eyes. Subjects in the hot condition also perceived air quality to be worse and reported SBS symptoms more often than subjects in the 22℃ condition. However, there were no significant changes in blink rate, arterial CO_2, or cortisol levels.

3.8.3 Effects of Heat on Cognition

Heat can also have detrimental effects on cognition, as found by the study by Lan et al. (2011) (see paragraph 3.8.1): subjects in the hot condition experienced increased mental load, and their performance of neurobehavioral tasks was decreased compared to subjects in the 22℃ condition. The authors assume that the negative effects on cognition, but also the effects on health and mood mentioned earlier are caused by physiological mechanisms, meaning they will happen regardless of whether one gets used to the perceived discomfort.

3.8.4 Effects of Coldness on Cognition

The effects of heat on human performance have been shown. But does coldness affect performance in the same way as heat? A study by Mäkinen et al. (2006) tried to answer this question. Ten young healthy adults were exposed to 25℃ for 90 minutes and then 10℃ for 120 minutes on ten successive days with constant humidity while physiological markers like skin temperature were measure. The subjects also performed cognitive tests in the last 20 minutes of each phase. The results were mixed, with positive effects on cognition explained with an increase in arousal, and negative effects explained with distraction. Generally, the results showed that "cold exposure had a negative effect on both simple as well as complex cognitive skills requiring sustained attention and concentration, verbal learning, numeric and symbolic facility, reasoning and operation of the working memory" (p. 174); however, sometimes response times were reduced, for example for logical reasoning, and overall efficiency was increased. There might have also been an accuracy-speed trade-off. The authors conclude that "the repeated cold exposures and observed changes in thermoregulation, thermal sensations and comfort had only a very small effect on cognitive performance" (p. 174), and "[n]o clear pattern of an effect of cold on a specific cognitive task (e.g. short-term memory, attention, executive functioning) was observed" (p. 175).

3.8.5 Thermal Manipulation of Hands

Although temperature was merely defined as air temperature at the beginning in this chapter, thermally influencing the body directly yields some interesting effects that might become relevant for collaborative learning: In a study by Kang et al. (2010), 30 college students touched either a warm or a cold pack with a temperature of 41 ℃ and 15 ℃, respectively, in their hands for just 10 seconds before playing an economic trust game. It was found that subjects who had previously touched the cold pack invested significantly less than the other subjects, indicating less trust in their partner.

In a similar study by Williams and Bargh (2008), 41 undergraduate students briefly held a warm or a cold cup of coffee before being asked to judge a person based on a written description of that person. Subjects who had held a warm cup judged the person as significantly warmer, i.e., more generous and caring in a questionnaire than those who had held the cold cup. In a second study with 53 participants, subjects who held a warm pad were more likely to choose a gift for a friend instead of for themselves, i.e., they were more altruistic than subjects who held a cold pad. The authors assume that this might be due to the same part of the brain – the insular cortex – processing the thermal and psychological version of warmth. It is noted that these effects happened without the subjects' awareness of the temperature's influence.

3.8.6 Summary

The summarized effects of temperature can be found in Table 3.7.

Further important points are:

- effects of heat on health and mood probably independent from subjective habituation
- little to no negative effects of coldness on cognition

3.9 Social Presence

It is a rather intuitive thought that social interaction can improve your life, e.g., by having friends support you in hard times or by being exposed to new ideas when you meet strangers. But just how important social interaction really is to human well-being is shown in a literature review by Cohen (2004). The authors argue that there are three aspects of social relationships which can influence human health through different mechanisms: social support through stress buffering, social integration through main effects, and negative interaction through causation of stress. In the following, we will examine each of those aspects.

Type	Mood	Health	Cognition	Behavior
heat	increased negative mood, decreased willingness to exert effort	increased heart rate and respiratory ventilation rate, decreased arterial oxygen saturation and tear film quality, increased occurrence of SBS symptoms	decreased mathematics scores (in children), increased mental load, decreased neurobehavioral performance	*n. e. f.*
warm hands	*n. e. f.*	*n. e. f.*	*n. e. f.*	increased trust and altruism, more generous judgments of others

Table 3.7: The summarized effects of temperature on human mood, health, cognition, and behavior according to the reviewed papers. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of temperature on the according human aspect were found in the literature review.

3.9.1 Effects of Social Support on Health

The first aspect of social relationships influencing health according to Cohen (2004), social support, is defined as "a social network's provision of psychological and material resources [intended to benefit an individual's ability to cope with stress]" (p. 676, italics changed). These resources can be instrumental resources such as financial help, informational resources such as advice, or emotional resources such as empathy, reassurance and the opportunity to vent. Support can provide solutions, reduce the perceived importance of a stressful event, and distract or encourage helpful coping mechanisms such as exercise. The mechanism by which this aspect can improve health is stress buffering. The negative effects of stress on health, for example harm caused by negative coping responses such as drinking alcohol or increased risk of physical disorders caused by prolonged activation of the sympathetic nervous systems, might be prevented if one's coping strength is increased by a belief that others will help you. Naturally, social support is only beneficial when the offered aid is adequate, e.g., money is unhelpful if you are stressed because your friend died, which is why emotional support is beneficial in most cases as opposed to instrumental and informational support. The literature review found several studies proving that more emotional support is associated with a lower rate of mortality; however, this mechanism has only been shown to improve health if the affected person is highly stressed. Interestingly, social intervention, i.e., support from strangers in the context of support groups did not seem to be as effective as natural social networks and might even be harmful to certain people. Social intervention seems, however, to be more effective if the subject does not already have a supportive social network.

3.9.2 Effects of Social Integration on Health

The second aspect of social relationships influencing health according to Cohen (2004), social integration, is defined as "participation in a broad range of social relationships" (p. 677) in a behavioral way, i.e., social activities, or in a cognitive way, i.e., through a "sense of communality and identification with one's social roles" (p. 677). The mechanism by which this aspect can improve health is called main effect, which refers to beneficial social connectedness in general, regardless of whether one is currently under stress. Examples for this mechanism are social controls, peer pressure, and taking care of yourself because you feel responsible for others in your social group, which can lead to a sense of identity, stability, purpose, belonging, and self-worth by fulfilling role concepts and group expectations. The literature review finds this aspect to benefit health by helping regulate emotions, reducing psychological despair and increasing motivation to take care of yourself; it might even enhance the immune system. The authors also found that greater social integration are associated with lower rates of mortality, and that a greater number of social roles such as father, neighbor, and husband are associated with decreased susceptibility to the common cold for two different viruses, independently of immunity due to pre-exposure to the virus at baseline. However, the latter association might be caused by stress buffering, and generally, social integration does not act as a stress buffer.

3.9.3 Effects of Negative Interaction on Health

The third aspect of social relationships influencing health according to Cohen (2004), negative interaction, shows that social relationships can also be a source of stress and, thus, harm health through cognitive, affective, and biological stress responses. Examples for negative interaction are conflicts, exploitation, or feelings of loss. The authors found that people who were chronically stressed due to enduring social conflicts in their lives were more than twice as likely to develop a cold than people who were not chronically stressed, independently of pre-exposure immunity. The authors note, however, that these effects probably depend mainly on whether one perceives the environment as stressful.

3.9.4 Relevance of Personality

With interpersonal relationships it is conceivable that personality also plays a role in determining the effects of social interaction on humans. Therefore, the literature review by Cohen (2004) also examines whether personality traits such as extroversion or hostility matter more than one's social environment with regards to effects of social relationships on health. It was found that "hostile people are at greater risk for coronary artery disease and possibly other physical health problems" (p. 681), whereas sociability, i.e., "the quality of seeking others and being agreeable" (p. 681) was associated with greater resistance to developing colds, independently of pre-exposure immunity and virus type. The authors conclude that sociability is directly beneficial if it leads us to creating social connections, and that the previously mentioned benefits might "just be a reflection of the benefits of sociability and not attributable to our social ties and interactions" (p. 681). As a consequence, simply gaining more social connections would not be beneficial to health if the person is not sociable. However, the social environment seems to be "at least partly independent" (p. 681) from personality traits.

3.9.5 Effects on Mood

We now know that social presence can affect physical health. However, it can affect mood as well, as shown in a literature review by Cacioppo and Hawkley (2009): the authors examined the effects of perceived social isolation, i.e., loneliness. The authors stress that perceived loneliness is not only influenced by mere network size, but also by other factors such as culture, childhood environment, and physical disabilities. Loneliness was found to increase negativity such as bad mood, anxiety, and anger, and decrease pleasure when viewing positive depictions of social interaction. Lonely people also demonstrate a heightened sensitivity to perceived social threats and other negative social stimuli such as facial expressions indicating pain. As loneliness is also associated with a confirmatory bias in social cognition, lonely people can become trapped in a vicious cycle of expecting bad social outcomes, acting more coldly and less charitable towards others, seeing people fulfill those negative expectations, feeling confirmed and, as a consequence, more motivated to avoid social interaction.

3.9.6 Contagion of Loneliness

Loneliness might be contagious: in the literature review by Cacioppo and Hawkley (2009), it was found that loneliness occurs in clusters and spreads within social networks, moving "lonely individuals closer to the edge of social networks over time" (p. 451). In other words, social contacts of a lonely person tend to become lonelier over time, especially when their friendship to the lonely person is reciprocal or when they are physically close. These results were independent from symptoms of depression. Thus, this contagion effect threatens social cohesion, causing social contacts of lonely people to drive lonely people away in order to protect the rest of the network, making lonely people objectively lonelier.

3.9.7 Effects of Loneliness on Cognition

The literature review by Cacioppo and Hawkley (2009) (see paragraph 3.9.5) also found loneliness to be a risk factor and potential contributor to numerous detrimental effects on cognition, such as poorer cognitive performance, faster cognitive decline and Alzheimer's Disease, even when controlling for depressive symptoms, as well as poorer executive functioning, i.e., a decreased capacity to control one's emotions, attention and behavior. Surprisingly, this was found to be true even for the mere belief that one will be socially isolated in the future.

3.9.8 Effects of Collaborative Learning on Cognition

With regards to individual learning, the social presence aspect refers to socially interacting in a learning context, i.e., collaborative learning. The primary question here is whether collaborative learning benefits learners and improves their performance as opposed to learning individually. Kirschner, Paas, and Kirschner (2009) found that, when task complexity, i.e., the number of interacting information elements is high, and thus, cognitive load is high as well, collaborative learning becomes more effective and efficient than individual learning, meaning that performance increases with less effort. This is thought to be the case because the cognitive load can be shared and, as a result, reduced for each participating learner. Furthermore, the increased cost of communicating, organizing, and recombining the divided information is "minimal compared to the gain achieved by this division of labor" (p. 31). However, for low-load tasks such as recall tests which one person can easily perform on their own, this additional cost can outweigh the benefits of reduced cognitive load, making individual learning more efficient. Thus, collaborative learning does not automatically guarantee that students learn more efficiently. Positive effects of collaborative learning for students are being more engaged and retaining information for a longer period of time, whereas negative effects include ineffective communication of information only known by individuals, and the risk of social loafing, i.e., benefiting off of others' work without contributing any work.

In a study, Kirschner, Paas, and Kirschner (2010) confirmed the previously mentioned hypothesis, the so-called Collective Working Memory Effect which states that

> "group members can make use of each others' WM [working memory] capacity by sharing the cognitive load imposed by a task, to process information elements deeply and construct higher quality schemas in their LTMs [long-term memories] than learners working individually" (p. 616).

In the study, 83 high school students and their relationship between cognitive load with individual and collaborative learning was examined. The students studied with either high or low complexity tasks in either groups of three students or individually before taking a test individually. The results revealed that,

> "[a]lthough groups achieved higher performance, invested less mental effort and were, thus, more efficient than individuals when learning from the high complexity learning tasks, individuals performed equally well, invested the same amount of mental effort, and were equally efficient on the low complexity learning tasks" (p. 621),

indicating that learning with low complexity tasks is suitable for individual learners, whereas high complexity tasks might be more appropriate for collaborative learning. The authors stress that group learners did not experience any negative effects of the additional communication costs on low complexity tasks, as opposed to the previous literature review. This, however, might have been the case because off-task communication in the learning groups was not allowed, which is not a representative situation for most learning groups.

Learning in groups might affect germane load levels as well: A study by Costley and Lange (2018) examined semi-formal learning, defined as "students [engaging] in learning for the purposes of doing well in a specific class, but outside of the parameters of specific directions from the instructor" (p. 69). The researchers asked whether semi-formal learning had an effect on the relationship between motivation and germane load, i.e., cognitive load that is "caused by information and activities that foster learning processes" (Kirschner, Paas, and Kirschner 2009, p. 40). 2042 college students participating in online classes filled out an online survey on learning preferences and behavior at the end of the semester. 52% of participants reported having offline interaction with other students. It was found that students with higher levels of intrinsic goal orientation, i.e., internally driven students, were more likely to interact offline and, if they did, they had statistically significantly higher levels of germane load. The strongest relationship with germane load was found for the following interactions: studying together, sharing notes, and talking about contents of the class. Generally, the results indicate that "as levels of group work increase, the strength of relationship between intrinsic goal orientation and germane load decreases" (p. 79). In other words, although group work was beneficial to all students, "students with lower levels of motivation benefited more than students with high levels of motivation" (p. 68).

3.9.9 Summary

The summarized effects of social presence can be found in Table 3.8.

Further important points are:

- individual learning perhaps preferable for simple tasks, collaborative learning for complex tasks
- collaborative learning recommended for non-intrinsically motivated students
- loneliness might be contagious
- personality partly determines effects of social environment

3.10 Discussion

We have now gained an overview on the possible effects that the environment can have on us. These findings are summarized in Tables 3.9, 3.10, and 3.11. We have also examined the effects of the environment on individual learning in particular. These effects, categorized by task type, are composed in Tables 3.12 and 3.13. Our next questions will be: is there any relationship between an environmental aspect's effect on humans in general and its effects on individual learning, i.e., does the effect on humans in general explain all or part of the effect on the learning process (RQ03)? And secondly, what conclusions for our framework can we draw based on our findings, i.e., what are the recommendations for an ideal learning environment according to each environmental aspect (RQ04 and RQ05)? In this chapter, I will answer both of these questions for each environmental aspect.

Many of the mentioned studies examined the effects of the environment on different areas of humans. Though some studies had special categories such as the effects of noise on introverts compared to extroverts or the effects of thermal manipulation of hands, most studies examined the effects on four areas: mood, health, cognition, and behavior. The summarized effects sorted by these four categories can be found in Tables 3.9, 3.10, and 3.11. For the discussion, behavior is not relevant, since we are investigating effects on *individual* learning, i.e.,

Type	Mood	Health	Cognition	Behavior
social support	*n. e. f.*	lower rate of mortality (for highly stressed people), perhaps decreased susceptibility to colds	*n. e. f.*	*n. e. f.*
social integration	more regulated emotions, reduced despair, increased motivation to take care of oneself	lower rate of mortality, perhaps decreased susceptibility to colds	*n. e. f.*	*n. e. f.*
negative interaction	stress	increased susceptibility to colds	*n. e. f.*	*n. e. f.*
loneliness	increased negativity, anxiety, anger	*n. e. f.*	increased risk of poor cognitive performance, faster cognitive decline, Alzheimer's Disease, and poor executive function	heightened sensitivity to perceived social threats
collaborative learning	increased engagement	*n. e. f.*	longer retention of information, increased performance on complex tasks	risk of social loafing

Table 3.8: The summarized effects of social presence on human mood, health, cognition, and behavior according to the reviewed papers. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of social presence on the according human aspect were found in the literature review.

learning on your own. Therefore, we will focus on the categories mood, health, and cognition in the following, except for the aspect social presence, since behavior is relevant for collaborative learning in which you interact with others. For each aspect, we will first summarize the effects of the environment, then examine the relationship between general effects and effects on individual learning, and finally, formulate recommendations for the frameworks.

Aspect	Type	Mood	Health	Cognition	Behavior
Noise	• intermittent, unpredictable noise • irrelevant speech, vocal music	increased annoyance, stress, anxiety (Kjellberg 1990)	• increased arousal (Kjellberg 1990) • increased diastolic blood pressure (Kjellberg 1990) • long-term: hypertension (Kjellberg 1990)	• impaired memory (Kjellberg 1990; Szalma and Hancock 2011; Reinten et al. 2017) • superficial processing of text (Kjellberg 1990) • decreased accuracy (Szalma and Hancock 2011) • esp. in introverts (Standing, Lynn, and Moxness 2013)	• less helpful towards other people (Kjellberg 1990) • orienting, defensive, or startle reflex (Kjellberg 1990)
	moderate ambient noise	*n. e. f.*	*n. e. f.*	increased performance on creativity tasks (Mehta, Zhu, and Cheema 2012)	*n. e. f.*
	continuous noise	*n. e. f.*	increased sleepiness (Kjellberg 1990)	performance on simple tasks unaffected (Kjellberg 1990)	*n. e. f.*
Light	6500K	• increased alertness (Chellappa et al. 2011) • increased well-being (Chellappa et al. 2011)	• influence melatonin levels (Chellappa et al. 2011) • increased visual comfort (Chellappa et al. 2011)	increased performance (Chellappa et al. 2011; Mott et al. 2012)	*n. e. f.*
	daylight	increased alertness (Heschong 1999)	• regulate melatonin levels (Heschong 1999) • contribute to entrainment (Heschong 1999) • vitamin D production (Heschong 1999; Boyce, Hunter, and Howlett 2003) • tissue damage (Boyce, Hunter, and Howlett 2003) • more/less eye strain (Boyce, Hunter, and Howlett 2003)	increased performance in children (Heschong 1999)	*n. e. f.*
	non-synchronized circadian rhythm	*n. e. f.*	*n. e. f.*	decreased performance (Wright et al. 2006)	*n. e. f.*

Table 3.9: The summarized effects of the environmental aspects noise and light on humans according to the reviewed papers, categorized by the aspects human mood, health, cognition, and behavior. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of the environmental aspect on the according human aspect were found in the literature review. For noise, the intensity and duration are of little relevance (Szalma and Hancock 2011) and negative effects can be mitigated through information (Paulus and Matthews 1980). For light, distraction through glare is possible (Boyce, Hunter, and Howlett 2003).

Aspect	Type	Mood	Health	Cognition	Behavior
Color	high-saturated	• stress (Kutchma 2003; W. Daggett 2008) • less depression, confusion, anger in females (Kwallek et al. 1996) • decreased alertness and job satisfaction (Kwallek et al. 2005)	• effects on heart rate and respiration (Gaines and Curry 2011) • fatigue (W. Daggett 2008)	• decreased error rate (Kwallek et al. 1996; Kwallek and Lewis 1990) • increased performance on detail-oriented tasks (red) and creativity tasks (blue) (Mehta and Zhu 2009)	*n. e. f.*
	low-saturated	• depression, confusion, anger in females (Kwallek et al. 1996) • increased alertness and job satisfaction (Kutchma 2003)	*n. e. f.*	increased error rate (Kwallek et al. 1996; Kwallek and Lewis 1990)	*n. e. f.*
Smell	rosemary	• elevate/maintain good mood (Moss et al. 2003) • mixed evidence on alertness (increased: Moss et al. 2003; decreased: Ilmberger et al. 2001)	*n. e. f.*	increased performance of memory and cognition (Moss et al. 2003)	*n. e. f.*
	lemon	increased alertness (Akpinar 2005)	*n. e. f.*	increased performance of memory and cognition (Akpinar 2005)	*n. e. f.*
	lavender	• elevate/maintain good mood (Moss et al. 2003) • little effect on alertness (Ilmberger et al. 2001)	*n. e. f.*	decreased memory performance (Moss et al. 2003)	*n. e. f.*
Space	crowdedness	• annoyance (Epstein, Woolfolk, and Lehrer 1981) • stress (Ulrich et al. 2018) • negative mood (Epstein, Woolfolk, and Lehrer 1981; Karlin, Rosen, and Epstein 1979)	physiological arousal (Epstein, Woolfolk, and Lehrer 1981)	decreased performance (Karlin, Rosen, and Epstein 1979; Paulus and Matthews 1980)	increased aggressiveness (in mentally ill people) (Ulrich et al. 2018)
Air Quality	poor ventilation	*n. e. f.*	SBS symptoms (Sundell et al. 2011)	• decreased cogitive performance in children (Wargocki et al. 2005) • decreased performance (Haverinen-Shaughnessy and Shaughnessy 2015)	*n. e. f.*
	high CO_2 levels	*n. e. f.*	*n. e. f.*	decreased performance on decision-making tasks (Satish et al. 2012)	*n. e. f.*

Table 3.10: *Table 3.9 cont.* The summarized effects of the environmental aspects color, smell space and air quality on humans according to the reviewed papers, categorized by the aspects human mood, health, cognition, and behavior. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of the environmental aspect on the according human aspect were found in the literature review. Color can also impact the perception of room spaciousness (Kwallek 1996). For smell, effects are possibly connected to one's personal view on the scent (Ilmberger et al. 2001). The effects of lemon were only documented for children (Akpinar 2005). For space, negative effects can be mitigated through information (Paulus and Matthews 1980).

3.10.1 Noise

It has been shown that noise can have many detrimental effects on human mood, health, behavior, and cognition. Effects on mood include annoyance and stress. Effects on health include an increased arousal level and long-term effects such as hypertension. Effects on behavior include becoming less helpful towards other people. Effects on cognition include impairment of memory, superficial processing of text, decreased accuracy, and in certain cases increased creativity. The most negative effects seem to be caused by intermittent, unpredictable, uncontrollable noise which is especially distracting and annoying since it is hard or impossible to get used to it or to prepare for it. Irrelevant speech is very distracting as well and harmful to verbal memory as it disrupts the phonological loop. Continuous noise does not seem to affect simple tasks such as proofreading. The intensity and duration of noise seem to be less relevant in determining the impact, unless the noise is loud enough to elicit a defensive or startle reflex. The maximum adaptability theory seems to best describe the effects of noise on cognitive performance.

The health effects of noise seem unlikely to be related to its effects on cognition, unless perhaps raised diastolic blood pressure damages the brain. Increased physiological arousal might lead to decreased accuracy or superficial processing of text by affecting a learner's ability to concentrate. However, it seems more likely that the health effects are not the original cause of the cognition effects and that they are, instead, a result of the effects on mood such as stress and anxiety as they could make a person restless. These mood effects, on the other hand, are probably a direct consequence of the distractive properties of noise: especially if intermittent and unpredictable, noise can elicit an orienting response which causes a person to focus with their senses on the noise. Even if the person does not look up, the person's thought process might get disrupted in order to process the noise and think about its possible source. This is a helpful reaction in many cases and can prevent us from danger because it enables us to hear, for example, a warning from someone or a siren. But if a learner is repeatedly interrupted for irrelevant reasons, i.e., if there is no danger and the noise source is of no importance to the learner, they might become annoyed or anxious if they are unable to get used to the noise, as is the case with intermittent and unpredictable noise which, as we have seen, is most distracting. This annoyance could then have a detrimental effect on the learner's motivation and endurance and, as a result, their cognition. Distraction might not just affect cognition indirectly through mood effects, but directly as well: for example, if a learner is reading a text and repeatedly loses their train of thought due to distraction, they might have forgotten the beginning of a sentence by the time they finish reading its second half because they were interrupted by a sound in the middle of the sentence. If this happens several times, the learner might only remember bits of content from the text, but not its greater statements. One literature review also found that noise makes a person focus on just the necessary aspects of a task (Kjellberg 1990); perhaps this is the case because noise uses up mental resources to execute the orienting response. This view is supported by Choi, Van Merriënboer, and Paas (2014) who write that noise takes away limited working memory resources from the cognitive process. This would explain the superficial processing of text and the decreased accuracy; it would also explain why simple tasks such as proofreading are not affected by continuous noise which only elicits an orienting response once when the noise starts. The literature review by Kjellberg (1990) also found that memory was impaired in learners who were told to memorize a list of items because they semantically connected less words to each other; this, too, could be explained by a decrease in available mental resources, because learners might need more mental resources to search for semantic connections between words. Similarly, speech might use up more mental resources than non-speech, because a person not only focuses their senses on the sound source but also processes the phonemes of the speech, and even the syntax and semantics if the spoken language is not foreign. All in all, distraction seems to cause most, if not all other negative effects of noise on humans in general and on individual learning. The only exception seems to be creativity which was, surprisingly, found to be enhanced by moderate levels of ambient noise.

According to Table 3.12, it is recommended that learners – especially introverts reading and learners working on vigilance, complex, memory, or auditory tasks – seek quiet learning environments, unless they are working on creativity tasks, in which case moderate ambient noise is desirable. If possible, they should avoid environments with irrelevant speech or intermittent and unpredictable noise due to its highly distractive properties as we discussed above. Continuous noise is acceptable if the student is doing simple tasks such as proofreading or if they are reading and an extrovert. If a student is studying with other people, they should be able to easily understand each other's speech, since trying to decipher another person's speech in a noisy environment might use additional mental resources due to having to filter out irrelevant sounds, leading to less available resources for learning. Last but not least, vocal music seems to impair cognitive performance similarly to irrelevant speech, so it is recommended that learners – if they choose to listen to music – listen to music without lyrics. Higher educational institutions should add sound absorbing material to their rooms and inform students about sources of noise to make the noise more predictable.

3.10.2 Light

Light was found to impact human mood, health, behavior, and cognition. Light, specifically short-wavelength light is especially important for entrainment of the circadian rhythm and regulation of melatonin levels. A non-synchronized relationship between sleep-wakefulness and the circadian rhythm due to inadequate lighting can impair learning directly as well as cause a person to get less sleep and, thus, decrease cognitive performance indirectly. Light with a temperature of 6500 K is not only associated with lower melatonin levels leading to faster reaction times in sustained attention tasks, but also increases alertness, well-being and visual comfort. Daylight is special in that it enhances production of vitamin D in humans which is beneficial to health, but it can also have negative effects such as tissue damage and eye strain. Warm-white light has been shown to increase a tendency to resolve interpersonal conflicts through collaboration.

With light, it is very clear from the findings that health effects are the dominant effect of light: melatonin levels and a synchronized relationship between sleep-wakefulness and the circadian rhythm have been shown to directly and indirectly affect human mood and cognitive performance. The direct hormonal mechanisms of light and melatonin on mood and cognition would go beyond the scope of this thesis; however, we have seen that a non-synchronized relationship between sleep-wakefulness and the circadian rhythm can lead to sleep deprivation especially in students who have fixed wake-up times and this lack of sleep was found to have a detrimental effect on grades, probably due to tired students not being able to concentrate on their work. Increased alertness due to 6500 K light might also have a positive effect on cognition by enhancing the learner's ability to focus on the task, but this seems to be a consequence of decreased melatonin levels or delayed DLMO rather than a direct effect of light (Chellappa et al. 2011).

As we have seen, the health effects of light and the resulting effects on mood and cognition depend largely on time of day and a person's bedtime. For example, 6500 K light can contribute to entrainment if a person is exposed to it in their subjective morning, but if they are exposed to it in the evening, it will cause delayed DLMO, perhaps leading the person to become sleepy later than usual and to go to bed later which can then result in a non-synchronized relationship between sleep-wakefulness and circadian rhythm if the person's wake-up time is fixed, i.e., if the person cannot sleep in the next day. However, this delayed DLMO can be acceptable, for example, if the learner usually goes to bed at 10 p.m. but has a deadline for an essay at midnight. In that case, 6500 K light might enhance his performance in the evening and the delayed DLMO would be an acceptable cost for this increase in cognitive performance, especially if the learner is able to sleep in the next day. Therefore, although 6500 K light is generally not recommended shortly before bedtime, it is recommended if cognitive performance is necessary at that time and outweighs the negative consequences. Further, in situations in which 6500 K light is recommended, learners should prefer daylight, and higher teaching institutions should install windows to let daylight into rooms due to its positive effects on health and cognition, though the effects on cognition were only found for children so far. Higher teaching institutions should also give learners the option to adjust the temperature of light. For collaborative learning, warm-white light is recommended to enhance collaboration. Independent from the type of lighting, light can act as a distractor by causing glare which should be avoided, e.g., by sitting behind the source of light or by putting curtains on a window.

3.10.3 Color

Color was found to have effects on human mood and cognition. Specifically, color has been shown to impact our stress levels and job satisfaction, influence our error rate in cognitive tasks and our creativity, and make a room seem more or less spacious. Certain colors, such as purple, yellow, and red were also perceived as distracting, though this did not decrease cognitive performance unlike distracting noise. Considering the prevalence of white offices, it is surprising how they seem to increase our error rate significantly in proofreading tasks and perhaps even decrease efficiency compared to other colors. Despite this, white offices were found to be very much preferred and perceived as non-distracting, perhaps because they cause little stress and increase job satisfaction in humans, or perhaps even due to their prevalence making people think they are appropriate and professional (Kwallek 1996).

Generally, a distractor can lead to decreased cognitive performance by using up mental resources, as was found for noise. Since colors rated distractive such as red and yellow have also been shown to cause stress, it is conceivable that mood effects determine whether a color is perceived as distracting. However, distracting colors had no negative effect on cognition: white offices, albeit being rated as least distracting, caused a subject to make the most errors compared to red and blue offices, indicating that distraction by color does not affect cognition in the same way as distraction by noise, even though Choi, Van Merriënboer, and Paas (2014) write that "[n]oise, whether visual or auditory, can be considered as a typical irrelevant environmental stimulus that takes limited WM [working memory] resources away from the learners' cognitive process" (p. 231). But by "visual noise", perhaps the authors mean busy and colorful patterns instead of monochromatic offices, and perhaps the reason why white offices increased the proofreading error rate is that they were too monotonous. Mehta, Zhu, and Cheema (2012), for instance, found that moderate levels of ambient noise increase creativity by inducing processing difficulty. Though the increased error rate in white offices was found in a proofreading task and not a creativity task, it is conceivable that a lack of distraction or stress caused by a color decreases the error rate in simple tasks with low processing difficulty such as proofreading by similar mechanisms. There is some evidence for this perspective: the study by Mehta and Zhu (2009) found blue computer screen backgrounds to increase creativity, and red ones to increase performance on detail-oriented tasks.

In general, the question which color is most suitable for a learning environment is hard to answer: white seems to be the least appropriate one when looking at mere performance, but considering not only the small availability of non-white rooms but also the negative effects on mood and job satisfaction of saturated colors, e.g., red and green, those colors might not be conducive to learning either as feeling stressed or not content with one's performance might have negative effects on a person's motivation to study. Generally, it was found that excessive use of color as well as understimulating environments should be avoided. Thus, the only sensible recommendation that can be made is to aim for balance: low-saturated colors like beige might be more beneficial for learning than white in order to avoid monotony, whereas high-saturated colors like red and blue seem to be most appropriate for highlighting to decrease monotony or for computer screen backgrounds – red for detail-oriented tasks and blue for creativity tasks. Large red and yellow areas are not recommended due to the stress and visual fatigue they cause.

3.10.4 Smell

Smell has been shown to impact human mood and cognition. Lavender and rosemary essential oils, when inhaled, were found to elevate or maintain good mood and increase contentedness. Rosemary also increased alertness and performance of memory, whereas lavender decreased performance of working memory. Lemon aroma seems to increase attention, enhance memory, and improve cognition – however, this result was obtained for children, so one should be cautious about applying these findings to adults.

As we have seen, strong scents were rated more intense and stimulatory than water, which might explain why these scents can enhance alertness. This could then improve cognitive performance, as alert learners might be able to focus more on their work. However, the effects of scents also seem to depend on the personal views of a person and whether they find the scent pleasant, which might indirectly affect cognition as well: an unpleasant smell might be perceived as distracting and, thus, impair learning, whereas a pleasant smell could create a good mood and impact learning by increasing the learner's motivation, patience, or endurance in the face of hurdles. All in all, it seems likely that a smell's effect on mood could influence cognition.

Generally, since the effect of smell might be connected to personal views more than to specific scents, it does not seem appropriate to give specific recommendations. This is also the reason why it is not recommended that higher teaching institutions use scents in rooms, as they might not benefit everyone and some may even dislike or be allergic to the scents. However, the effects of rosemary and perhaps lemon seem promising, so it is at least worth a try for students to find out whether those scents – or other scents that they personally like – benefit them. Lavender should be avoided as it was found to impair memory, despite its positive effects on mood. Generally, strong scents might be distracting in some cases, so learners should beware of this effect and stop the use of the essential oil if they feel distracted by it.

3.10.5 Space

Crowding was found to impact human mood, behavior, health, and cognition. Specifically, crowdedness can cause annoyance, negative mood, stress, aggressiveness, increase physiological arousal, and decrease cognitive performance. Social density might matter more than spatial density.

It is conceivable that the negative effects on mood such as annoyance and stress directly impair learning as they might decrease the learner's patience or willingness to put in effort. Physiological arousal might contribute to these negative feelings, indirectly impairing learning as well. It is also possible that crowding causes aggressive social encounters due to the negative mood which, as a result, is amplified; however, crowding was found to increase negative mood in situations without social interaction as well. Thus, behavioral effects such as aggressiveness are unlikely to be the cause of the other effects. Mood effects seem to be the most likely cause of at least part of the effects on cognition.

Generally, crowding should be avoided in an optimal learning environment. Unfortunately, this is not always possible. The good news, however, is that the negative effects of crowding might be easily avoided. One way to mitigate negative effects on mood seems to be closing your eyes as it decreases sensory stimulation and, thus, arousal. But this might be impractical for learners as they commonly have to read or write when studying, so this method is only suitable for situations in which students merely want to decrease their stress for a few minutes. A better way might be to educate the learner about the effects of crowdedness, as this has been shown to mitigate the negative effects of being crowded on cognition. For teaching institutions, it is recommended that they offer many rooms even if they are small, as opposed to just a few large rooms, as social density seems to have more of an impact on humans than spatial density. However, this might not be easily accomplished if the university was designed to have open learning spaces instead of small rooms; in this case, it is important for teaching institutions to keep in mind that "open learning spaces pose special requirements to climate and acoustics" (Merriënboer et al. 2017, p. 265). Regarding the resulting high social density, makeshift room dividers such as folding screens or nooks for studying might alleviate feelings of crowdedness and somewhat decrease social density. Generally, also considering the unclear effects of certain colors, it is recommended that higher teaching institutions involve students in the design process of learning spaces and let them try out different set-ups to evaluate their effectiveness in supporting the learning process (Merriënboer et al. 2017). Higgins et al. (2005), too, recommend "elements of flexibility and adaptability for new cohorts of learners and teachers, new curriculum demands and new challenges" (p. 37) and write that

> "there is an implication in many studies that the empowering process of re-designing and taking ownership would spill over into motivation and empowerment in other areas, encouraging creativity and experimentation in the curriculum, raising motivation towards academic and social goals" (p. 37),

and although this was written in regards to K-12 schools, it is conceivable that these concepts apply to college students as well. Folding screens and movable chairs and desks might be an easy way to give students more freedom in adjusting the spatial environment to their needs.

3.10.6 Air Quality

Air quality has been found to impact human health and cognition. Specifically, poor indoor air quality caused by low ventilation rates or high CO_2 levels seems to increase the prevalence of SBS symptoms such as headache and fatigue, and decrease decision-making performance to sometimes marginal and dysfunctional levels. Poor indoor air quality has also been shown to decrease cognitive performance in children as well.

It is conceivable that the negative effects of bad indoor air quality on health also have an impact on cognition: A person feeling tired and sick might have less endurance to work on challenging tasks and might not be able to focus on their studies if their symptoms distract them. If the symptoms become serious, a person might even become incapable of working. Therefore, it seems likely that the health effects also have an effect on cognition.

Poor indoor air quality generally does not seem conducive to learning, and should therefore be avoided by learners and higher teaching institutions. This can be done by installing windows and opening them regularly, as well as installing and properly maintaining ventilation systems.

3.10.7 Temperature

Temperature has been shown to impact human mood, health, cognition, and behavior. Heat seems to increase not only prevalence of SBS symptoms but also mental load, negative mood, heart and respiratory ventilation rate, and decrease arterial oxygen saturation, tear film quality, performance on neurobehavioral tasks, and willingness to exert effort. These effects are assumed to be independent from subjective habituation. Coldness, on the other hand, only had a slightly negative effect on cognitive performance. Just like poor indoor air quality, heat has been shown to decrease cognitive performance in children as well.

It seems that heat has a direct effect on health. As hypothesized by one study, there might be physiological mechanisms which cause several of the observed effects on health and mood; and as argued in paragraph 3.10.6 above, illness could have a negative effect on cognition. The effects on mood could exacerbate these effects: a person who is not only feeling sick but also in a bad mood and not very willing to exert effort will probably have even less endurance than someone who is merely feeling sick, and might therefore struggle even more with challenging tasks and hurdles.

Heat seems to be very detrimental to learning due to its many negative effects on mood and health, and should therefore be avoided by learners and higher teaching institutions. This can be done by wearing appropriate clothing and staying indoors in hot summer weather. Effects of temperature changes in subjects' hands yielded some interesting results which might be relevant for collaborative learning: warmth was found to make subjects more trusting, altruistic, and more generous in judgments of other people, whereas coldness decreased interpersonal trust. Thus, warming one's hands might be an effective way of ensuring harmonious and cooperative collaborative learning.

3.10.8 Social Presence

Social presence and interaction have been shown to affect human mood, health, behavior, and cognition. Specifically, emotional support, sociability, and social integration were associated with a lower rate of mortality and an increased resistance to developing colds. Hostility and enduring social conflicts were associated with an increased risk of developing coronary artery disease and colds. Loneliness had many detrimental effects, including poorer cognitive performance, faster cognitive decline, poorer executive functioning, increased negativity, and heightened sensitivity to social threats in combination with confirmatory bias. Collaborative learning, under certain conditions, cause learners to be more engaged and retain information for a longer period of time, assuming that no social loafing occurs.

It is possible that the mood effects of social presence have an impact on cognition, as being in a bad mood could make a person less willing to exert effort or deal with hurdles that a learner might encounter, while being in a good mood and feeling engaged could increase a learner's motivation and endurance, leading to better learning outcomes. The health effects, on the other hand, seem unlikely to affect cognition, as they are long-term effects such as an increased rate of mortality, or other effects such as an increased risk of catching a cold, and while the thoughts of dying young or catching a cold might be troubling, for them to affect cognition would probably require that a learner is aware of the according statistics and thinks about them while studying which generally seems to be an unlikely scenario.

Studies have found collaborative learning to be especially beneficial for students with low levels of intrinsic motivation and for learning with high complexity tasks. It is therefore also recommended that higher teaching institutions offer space for collaborative learning. This includes flexible furniture so that students can adjust the furniture to their needs and, e.g., arrange chairs and desks accordingly (Merriënboer et al. 2017; Higgins et al. 2005). Tasks with low complexity seem more appropriate for individual learners. Although one study found no difference between collaborative and individual learners' performance in this case, the students were not allowed to have off-topic conversations which is unrealistic especially for semi-formal learning outside of school or university. Therefore, collaborative learning is not recommended for students learning with low complexity tasks.

3.11 Recommendations

We now understand the possible relationships between the environment's effects on humans in general and its effects on cognition. In the discussion, it was found that mood effects might be responsible for cognition effects for the aspects smell, space, and social presence; health effects might have an impact on cognition for the aspects light, temperature, and air quality; and the cognition effects of noise and color seem to be related to distraction more than to mood, health, or behavior effects. We also worked out recommendations for the two frameworks. However, it is unrealistic for a student to find a learning environment that matches all of the frameworks' criteria, and higher teaching institutions, too, have limited financial resources and, thus, might not be able to fulfill all recommendations. So if a student has to decide between two non-optimal learning environments with different advantages and disadvantages, which are the criteria according to which they can determine which learning environment is preferable?

Students go to a learning space to accomplish certain goals. If they feel that the environment is directly preventing them from accomplishing these goals, they will look for a different learning space. Therefore, uncontrollable disruptions most obvious to the student will probably elicit the greatest desire in them to leave the place. The most obvious uncontrollable environmental disruption is probably distraction. Mood and behavioral effects might be less obvious since a person's mood and behavior can be influenced by a variety of factors besides the environment, such as negative self-talk, and are also somewhat controllable by thoughts. And while health can be uncontrollable, e.g., due to inherited diseases, one is still able to alleviate certain symptoms, e.g., by taking pain killers, and some people might also not be aware of the relationship between the environment and certain symptoms, especially since many diffuse symptoms can also have other causes such as viruses, making health effects less obvious to learners. Distraction, on the other hand, is generally not controllable, especially if you are not at home; for example, it is generally not socially accepted to tell people in a public park to stop talking. Additionally, the cause – the environment – is especially clear with distraction, since it is a direct effect of the environment. Therefore, a student feeling distracted will probably be most likely to leave a learning space compared to a person feeling sick or being in a bad mood due to the environment.

However, is this a valid reason to make a distraction-free environment the top priority? On the one hand, it is, because if a learner is convinced that the environment is not supporting him in accomplishing his goals, he will most likely leave. On the other hand, since the framework's aim is to make recommendations based on empirical studies, one should take into account the effects on cognition and not just the student's perception of them. As we have seen with white offices, subjects' perception of the environment's effects on their cognition does not always accurately reflect the environment's actual effects. Therefore, we will also examine which effects might be most detrimental to cognitive performance. As we have seen in the previous discussion, mood and health effects might have an impact on cognition. It was argued that long-term health effects probably have little to no impact on cognition, whereas short-term health effects could potentially be devastating if they make a person incapable of working. However, this is an extreme case and will probably not occur often. Generally, light to moderate symptoms probably affect cognition in a similar way as negative mood by decreasing a learner's endurance, patience, or willingness to invest effort. However, as we have argued above, mood and, to a certain degree, health are somewhat controllable so that being in a negative mood or feeling sick might not necessarily affect cognition. Distraction, on the other hand, and especially distraction by noise directly uses up mental resources. Irrelevant speech, for instance, directly disrupts the phonological loop when trying to memorize verbal information, and intermittent, unpredictable noise elicits an orienting response which, too, probably uses up mental resources. Therefore, distraction might be not just be perceived by learners as the most obvious uncontrollable environmental disruption, but might actually be considered the most detrimental effect that the environment can have on learners.

For these reasons, it seems paramount for students seeking a learning environment that distractions are kept at a minimum, even if this means that the learning environment is inadequate regarding other aspects. This means primarily that the learning environment should be quiet and especially have no intermittent, unpredictable sound or irrelevant speech. Color is an exception as studies indicate that monotony in color might be more detrimental to cognition than a monochromatic office with a saturated color. Environmental aspects affecting cognition mainly through mood or health effects, on the other hand, might rank lower in importance. However, priorities are slightly different when making recommendations for higher teaching institutions: although health effects of short-term exposure to inadequate light or poor ventilation might not be as severe as distraction by noise, teaching institutions have the ability to plan for the longer term, and therefore, appropriate light, temperature, and indoor air quality should be more important to them than to students in order to prevent long-term health effects. Thus, the priorities of the recommendations depend not only on their ability to improve learning, but also on the approach of the person for which the framework is intended.

Below are the two frameworks containing the recommendations that we worked out above.

3.11.1 Framework for Students

1. Seek a quiet environment, especially if you are reading and an introvert or working on a vigilance, complex, memory, or auditory tasks. If you have to decide between a noisy, but otherwise good learning environment and a quiet, but for other reasons inadequate learning environment, choose the latter, unless you are working on a creativity task, in which case you should seek moderate ambient noise, e.g., in a cafe. Try to avoid intermittent, unpredictable noise, such as noise coming from a construction site near you. Try to avoid studying near talking people, especially if they are close enough to you that you can understand what they are saying. This, of course, does not apply if you are studying with other people, in which case you should make sure that the environment is quiet enough that you can easily hear and understand each other. If you are doing simple tasks such as proofreading, continuous sounds such as traffic noise is acceptable, but a quiet environment would be preferable nonetheless. Note that if your environment is noisy, you might experience increased discomfort or anxiety. Though silence is generally preferable, if you do choose to listen to music, listen to instrumental music without any lyrics.

2. Seek daylight if possible or, alternatively, short-wavelength light with a temperature of about 6500 K, i.e., cold light. However, if it is a couple of hours before your bedtime, choose lighting with a lower temperature such as 3000 K, i.e., warm light. The only exception to this is if you must work and perhaps stay up late; in this case, choose cold light as well. If you are studying with other people, warm-white light is preferable. In any case, try to avoid glare, e.g.,

by positioning yourself in front of the light source so it doesn't directly hit your eye or by putting a curtain on the window.

3. Seek an environment with a well-balanced color scheme. Completely white rooms might not be beneficial even though they are common. If available, try a beige or tan colored room instead, ideally with some green or blue accents, e.g., in furniture to decrease monotony. If you are working on a creativity task on your computer, set up a blue background screen on your computer. Choose a red background if you are working on a detail-oriented task such as memorizing information. If you feel bored or overwhelmed by the colors, try switching to a room with a different color scheme. Avoid large red or yellow areas.

4. If you enjoy rosemary or lemon scent, try adding a few drops of essential oil to a diffuser or something similar and see if you feel that it improves your learning, especially if you are in a bad mood. Other scents might have a positive impact on your learning too if you enjoy them. However, if you start to feel distracted by the scent, stop using it or decrease the amount of essential oil you use. Avoid lavender essential oil.

5. Seek an uncrowded room with as few people in it as possible. Note that if your environment is crowded, you might experience increased discomfort or anxiety. If you feel overwhelmed by how crowded your environment is and you are unable to find a less crowded area, try closing your eyes for a few minutes until you feel more relaxed.

6. Seek an environment with plenty of fresh air and a comfortable temperature. If you cannot adjust the temperature, make sure you are wearing appropriate clothing. Try to especially avoid heat, i.e. you should generally study indoors in summer. If you are studying indoors, rooms with openable windows are preferable. Make sure you keep them open if the weather and outside temperature allow it, or open them regularly for a few minutes. Especially if you start to feel any symptoms such as irritated eyes, nose and throat, symptoms of upper respiratory infections, nausea, dizziness, headaches, fatigue, or sleepiness and you do not know why, i.e., you are not ill as far as you know, get some fresh air by going outside if the weather is suitable or open the windows for a few minutes, and also make sure it is not too warm in your room – if it is, seek a cooler environment. If you are studying with other people, additionally make sure you and the other people are warm enough. If you are not, you can warm your hands with a heating pad or a warm cup of coffee or tea.

7. Seek a learning group if you have low levels of intrinsic motivation or if your work consists of mainly complex tasks. If you are studying with mainly simple tasks, prefer to study alone.

3.11.2 Framework for Higher Teaching Institutions

1. Add sound absorbing material to rooms, especially to rooms used for studying. If you know that there will be a source of noise near studying rooms, such as intermittent noise coming from a construction site or from repairs being done at the university, try to schedule classes to take place farther away from the source of noise, and if that is not possible, inform students about the disturbance and educate them on the possible effects of noise such as increased anxiety or discomfort.

2. Wherever possible, add large windows to rooms so that plenty of daylight can enter the room. Install light bulbs emitting short-wavelength light with a temperature of 6500 K, but if

possible, give students the option to adjust the light temperature. Rooms for collaborative learning should have warm-white light. Give students the option to avoid glare, e.g. by installing curtains or blinds.

3. Strive for balance when choosing a color scheme for rooms. Solely white rooms should be avoided. An example would be a beige or tan room with green or blue highlights, e.g. in furniture. Avoid large red or yellow areas.

4. It is recommended that no scents are distributed in rooms.

5. Many small rooms for studying are preferable to few large rooms. In large and commonly crowded rooms, educate students on the possible effects of crowdedness, such as increased anxiety or discomfort. If open learning spaces are not avoidable, it is strongly advised that the teaching institution ensures appropriate acoustics and ventilation; in this case, it is also recommended to set up folding screens or build nooks.

6. Maintain a good ventilation system with clean filters and few indoor pollutants. Ensure that CO_2 levels in rooms stay minimal. Ensure that rooms stay cool in summer. If possible, give students the option to adjust the temperature and to open the windows. Perhaps set up reminders for students to regularly open the windows, especially if they are experiencing SBS symptoms.

7. Offer space for collaborative learning.

8. When designing learning spaces, it is recommended to involve students in the design process so they can incorporate their needs and try out different plans in mock-ups to evaluate their effectiveness in supporting the learning process.

9. It is recommended to offer flexible, movable furniture in learning spaces so that students can adjust them to their needs, e.g., for collaborative learning.

3.12 Limitations

The greatest limitation of this literature review becomes obvious when looking at Table 3.12: learning is not clearly defined. This was done in order to not unnecessarily restrict the field of suitable papers. It was difficult finding studies on adult cognition alone, and being attached to a specific definition of cognitive performance would have further reduced the amount of suitable papers. The downside of this practice is that the effects found in studies are hard to compare since the studies did not assess cognitive performance with the same types of task. This resulted in a very big table with numerous task types but many empty cells for task types for which the effects are unknown. Some task types might even be irrelevant if college students do not usually perform them when studying. Some studies did not have or mention specific task types at all, for example, because they compared academic performance, i.e., grades. This is unfortunate for the framework and the Learning Environment Wizard as well, since it is often impossible to make recommendations for specific task types or specific locations. The point of the Learning Environment Wizard is to guide the user through the framework and to present him with only relevant information in the end, but if a recommendation is not specific to task type or location, there is nothing through which to guide a user and the wizard becomes unnecessary.

Certain environmental aspects had similar difficulties: just one study on crowding, for example, differentiated between social and spatial density, whereas the others did not. And different studies examined different causes of poor air quality such as ventilation rates or CO_2, whereas other causes such as indoor pollutants were not specifically examined, making it hard to compare the results.

Another limitation is that the general effect size of the environment is unclear: it is hard to tell how much variability in learning outcomes is due to the environment. This is in part due to the inconsistency regarding the definition of learning mentioned above, and in part because more complex interactions between the environmental aspects were not investigated in this thesis. The latter is an important factor that should be examined and could have an effect on the frameworks as well; Higgins et al. (2005), for example, calls attention to how sound-absorbing hangings meant to improve room acoustics could worsen air quality by gathering dust.

Generally, there are many more realizations of the environmental aspects that could be examined in studies in order to make the frameworks and the wizard more helpful. For noise, for instance, just one type of instrumental music was examined in one study; but there are many different types of instrumental music which vary in speed, rhythm, and key and which, thus, might have different effects on cognition. For color, only monochromatic offices were examined which are generally uncommon unless they are white; realistically, a room will have many differently colored objects in a room, and there are many more ways to use color, for example by combining colors, by using different patterns, or by using colored paper. For smell, the studies in this literature review only examined the effects of essential oils; but we learned nothing about other smells which are more common in life, such as the smell of food which would probably have some kind of distracting or disturbing effect on hungry or nauseous people. By examining merely certain realizations of the according environmental aspect, especially when those realizations are uncommon in the real world, the results become much harder to apply.

3.13 Conclusion

In this chapter, we found that studies provide evidence of noise, light, color, smell, space, temperature, air quality, and social presence affecting humans in various areas such as their mood, health, behavior, and cognition in numerous ways. A summary of the effects of the environment can be found in Tables 3.9, 3.10, and 3.11 as an answer to RQ01. Task-specific effects of the environment on individual learning can be found in Tables 3.12 and 3.13 as an answer to RQ02.

In the discussion of RQ03, it was argued that the environment's effects on humans in general might explain at least part of the effects on individual learning. Furthermore, we reasoned that distraction through noise might be the most detrimental effect, whereas poor health and negative mood might have less detrimental effects on individual learning, at least in the short term.

Finally, we worked out two frameworks, one for students seeking optimal learning environments (see paragraph 3.11.1) as an answer to RQ04, and one for higher teaching institutions seeking to provide good learning environments (see paragraph 3.11.2) as an answer to RQ05. They contain recommendations on how to minimize negative environmental effects on learning and exploit their advantages to facilitate individual learning. Since at least two studies were examined per environmental aspects and since at least half of each aspect's studies were conducted on adults, usually on college students, it is assumed that the frameworks are sound and highly applicable for college students.

However, several difficulties were encountered as well: the main problem was that learning was not clearly defined which makes comparisons of effects and giving specific recommendations difficult. Further problems included similar inconsistencies in definition in some other aspects and the fact that no interactions between the environmental aspects were investigated. Although the frameworks are assumed to be applicable, there are many realizations of certain environmental aspects about which we learned nothing, despite those realizations sometimes being much more common in the real world than the realizations examined in the studies, which makes the application of the findings somewhat difficult. Without a doubt, there are many more facets of the environment to investigate. For an overview on suggestions for further research, see chapter 6.2.

All in all, it is indisputable that the environment affects us. But how are we to rate the environment's influence? Higgins et al. (2005) write on the effects of the environment on school children that

> "[t]here is strong, consistent evidence for the effect of basic physical variables [...] on learning. [...] Once minimal standards are attained, evidence of the effect of changing basic physical variables is less significant. [...] Beyond the level of meeting basic standards, there is not enough evidence to give clear guidance on how to set priorities for funding, or to evaluate the relative value for money of different design initiatives." (p. 7, p. 36)

For the studies investigated in this thesis, it is hard to determine the degree of impact of the environment as a whole on individual learning, especially since interactions between the environmental aspects were not examined at all despite "[t]he interactions of different elements [being] as important as the consideration of single elements" (Higgins et al. 2005, p. 22). However, Earthman (2017) who examined studies on building condition – an environmental aspect not investigated in this thesis – came to an important conclusion. According to the author, most studies found building condition of K-12 schools to account for merely 3 to 10% of difference in student scores (Earthman 2017), whereas out-of-school variables such as family income account for about 60% of variance in student achievement (Berliner 2014). However, as Earthman (2017) correctly states, "when compared with the variance in student learning that can be attributed to school influence, these percentages [of 3-10%] are of importance. At least these percentages represent an area in which school authorities have control" (p. 11). So in the end, the environment might not account for much difference in learning outcomes – but why not take control where we can effectively enhance individual learning?

Aspect	Type	Mood	Health	Cognition	Behavior
Temperature	heat	• increased negative mood (Lan et al. 2011) • less willingness to exert effort (Lan et al. 2011)	• SBS symptoms (Lan et al. 2011) • increased heart/respiratory ventilation rate (Lan et al. 2011) • decreased arterial oxygen saturation (Lan et al. 2011) • decreased tear film quality (Lan et al. 2011)	• decreased cognitive performance in children (Haverinen-Shaughnessy and Shaughnessy 2015) • decreased performance on neurobehavioral tasks (Lan et al. 2011) • increased mental load (Lan et al. 2011)	warm hands: • more altruistic (Kang et al. 2010) • more trusting (Williams and Bargh 2008) • more generous in judgments (Williams and Bargh 2008)
	coldness	*n. e. f.*	*n. e. f.*	no negative effects for coldness (Mäkinen et al. 2006)	*n. e. f.*
Social Presence	loneliness	increased negativity (Cacioppo and Hawkley 2009)	*n. e. f.*	• decreased performance (Cacioppo and Hawkley 2009) • faster decline (Cacioppo and Hawkley 2009) • decreased executive functioning (Cacioppo and Hawkley 2009)	increased sensitivity to social threats (Cacioppo and Hawkley 2009)
	social integration and support	*n. e. f.*	• decreased rate of mortality (Cohen 2004) • increased resistance to developing colds (Cohen 2004)	*n. e. f.*	*n. e. f.*
	collaborative learning	being more engaged (Kirschner, Paas, and Kirschner 2009)	*n. e. f.*	retain information longer (Kirschner, Paas, and Kirschner 2009)	risk of social loafing (Kirschner, Paas, and Kirschner 2009)

Table 3.11: *Table 3.9 cont.* The summarized effects of the environmental aspects temperature and social presence on humans according to the reviewed papers, categorized by the aspects human mood, health, cognition, and behavior. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of the environmental aspect on the according human aspect were found in the literature review. The effects of temperature might be independent from subjective habituation (Lan et al. 2011). Collaborative learning seems to be especially helpful for learners working on high complexity tasks (Kirschner, Paas, and Kirschner 2009; Kirschner, Paas, and Kirschner 2010) and for learners with low levels of intrinsic motivation (Costley and Lange 2018).

Task Type	Noise	Light	Color	Smell	Space	Air Quality	Temperature	Social Presence
Simple	• unaffected by continuous noise (Kjellberg 1990) • speed of typing slower in absorbent room (Reinten et al. 2017)	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*	perhaps decreased (colab. learning) (Kirschner, Paas, and Kirschner 2009)
Complex	decreased (Paulus and Matthews 1980)	*n. e. f.*	*n. e. f.*	*n. e. f.*	decreased (Paulus and Matthews 1980)	*n. e. f.*	*n. e. f.*	improved (colab. learning) (Kirschner, Paas, and Kirschner 2009; Kirschner, Paas, and Kirschner 2010)
Memorization	• impaired (Kjellberg 1990; Szalma and Hancock 2011) • impaired by vocal, not instrumental music (Alley and Greene 2008)	impaired (non-synchronized relationship) (Wright et al. 2006)	increased by red background (Mehta and Zhu 2009)	affected (Moss et al. 2003; Akpinar 2005)	*n. e. f.*	*n. e. f.*	*n. e. f.*	improved (colab. learning) (Kirschner, Paas, and Kirschner 2009)
Mathematical	*n. e. f.*	• impaired (non-synchronized circadian rhythm) (Wright et al. 2006) • improved (daylight) (Heschong 1999)	*n. e. f.*	*n. e. f.*	*n. e. f.*	affected in children (Haverinen-Shaughnessy and Shaughnessy 2015)	affected in children (Haverinen-Shaughnessy and Shaughnessy 2015)	*n. e. f.*
Creativity	increased by moderate ambient noise (Mehta, Zhu, and Cheema 2012)	*n. e. f.*	increased by blue background (Mehta and Zhu 2009)	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*

Table 3.12: The summarized effects of the environmental aspects noise, light, color, smell, space, air quality, temperature, and social presence on human cognition according to the reviewed papers, categorized by cognitive task type. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of the environmental aspect on the according task type were found in the literature review. Only those task types are listed that at least one of the reviewed papers examined. For effects on cognition with no specified task type, see Tables 3.9, 3.10, and 3.11.

Task Type	Noise	Light	Color	Smell	Space	Air Quality	Temperature	Social Presence
Reading	• superficial processing and impaired comprehension (Kjellberg 1990) • worse for introverts, extroverts unaffected (Standing, Lynn, and Moxness 2013)	• improved (6500 K) (Mott et al. 2012) • improved (daylight) (Heschong 1999)	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*
Proofreading	• unaffected by continuous noise (Kjellberg 1990) • worse performance in reverberant room (Reinten et al. 2017)	*n. e. f.*	more errors (light colors, esp. white) (Kwallek et al. 1996)	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*
Reaction-Time	unaffected by continuous noise if simple (Kjellberg 1990)	• impaired (non-synchronized circadian rhythm) (Wright et al. 2006) • improved in children (6500 K) (Chellappa et al. 2011)	*n. e. f.*	affected (Moss et al. 2003)	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*
Vigilance	affected perhaps even at low noise levels if signal complex (Kjellberg 1990)	*n. e. f.*	*n. e. f.*	affected (Moss et al. 2003; Akpinar 2005)	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*
Other	• sensory, motor: unaffected by continuous noise if simple (Kjellberg 1990) • auditory: possibility of negative effects (Kjellberg 1990) • speech processing affected (Reinten et al. 2017)	executive functioning: unaffected (6500 K) (Chellappa et al. 2011)	*n. e. f.*	*n. e. f.*	*n. e. f.*	*n. e. f.*	neurobehavioral: decreased (heat) (Lan et al. 2011)	executive functioning: decreased (loneliness) (Cacioppo and Hawkley 2009)

Table 3.13: *(Table 3.12 cont.)* The summarized effects of the environmental aspects noise, light, color, smell, space, air quality, temperature, and social presence on human cognition according to the reviewed papers, categorized by cognitive task type. The abbreviation "*n. e. f.*" stands for "no effects found" and indicates that no effects of the according realization of the environmental aspect on the according task type were found in the literature review. Only those task types are listed that at least one of the reviewed papers examined. For effects on cognition with no specified task type, see Tables 3.9, 3.10, and 3.11.

4 Implementation

In this chapter, I provide a comprehensive look in the implementation process of the Learning Environment Wizard. The aim of this website is to help students find an optimal learning environment. The wizard's theoretical basis is the framework for students from chapter 3.11.1.

4.1 Similar Apps and Websites

There are several existing websites and applications that help students find suitable places for studying. Table 4.1 presents a selection of similar apps and websites along with a short description. Most of them have been developed by universities and are only include locations on their campus or in their city; an exception to this is StudyPal. They often allow students to find nearby locations and to filter them according to certain factors, such as equipment and technology or noise, or to check availability of seats at a location. The most often considered environmental aspect is noise, followed by light and social presence. Especially Study Space Finder and Spacefinder consider those environmental aspects.

However, many other aspects, i.e., air quality, temperature, color, smell, and space are not taken into account on these websites. Even worse, although the websites give students the option to filter locations according to environmental aspects, they give the students no guidance in finding out which locations they should be looking for. Therefore, the usefulness in finding good learning environments is distinctly decreased, as students might choose bad learning environments, such as a noisy environment for proofreading.

Therefore, the Learning Environment Wizard will not only take all of the eight environmental aspects into account, but also offer guidance in choosing good learning environments according to the user's needs. This will be done in the form of a wizard so that users can quickly receive a recommendation without having to read through the whole framework. Although the location recommendations will be limited to Frankfurt, Germany, the wizard and its recommendations are universal and could be used by students from other universities as well if they can understand German.

4.2 Purpose of Website

The main purpose of this website was originally to help students find good learning spaces. However, as the frameworks were developed, it became clear that many recommendations were universal and did not allow for different specific recommendations depending on other factors, and so the wizard might not be very helpful to students in the long term. Therefore, the

Name	Description	Area	Features
SpaceScout[a]	mobile and web-based application from University of Washington Tacoma (UW Tacoma), USA	about 200 spaces in UW Tacoma and Seattle area	search for learning spaces, food, and tech items
StudyPal.co[b]	website and phone application, available for Apple and Android	for over 70 countries	• set your location and you get suggested study places, e.g. coffee shops and bookstores near you • mainly for finding study partners and tutors near you to study for standardized tests such as TOEFL
Study Space Finder[c]	website from University of Minnesota	University of Minnesota area	filter according to aspects such as technology (e.g. computer lab, printing), noise (e.g. quiet, chatter), seating (e.g. tables and chairs, individual desks), general features (e.g. natural light, group study), and campus
UCL Go![d]	application and website from University College London	University College London	• locate available study space, i.e. free desks on campus in real-time • devices using infra-red technology are installed under each desk and determine whether a desk is free
Spacefinder[e]	website from Cambridge University	Cambridge University area	• filter by study preference, atmosphere, noise levels, facilities • information on whether food allowed, wifi available, daylight, opening hours etc. • students can add tips to locations
Study Space[f]	website from University of Edinburgh	University of Edinburgh	• lists of study places sorted by categories e.g. accessibility, noise level, computer availability • also check library occupancy and desk availability

Table 4.1: Existing websites and applications similar to the Learning Environment Wizard. These websites and apps help students find good learning spaces near them.

[a] https://scout.uw.edu/seattle/
[b] https://www.studypal.co/
[c] https://studyspace.umn.edu/
[d] https://www.ucl.ac.uk/library/libraries-and-study-spaces/available-study-spaces
[e] https://spacefinder.lib.cam.ac.uk/
[f] https://www.ed.ac.uk/information-services/students/study-space

website was given an additional purpose: to enable students to review specific learning spaces. As of yet, only Goethe University libraries can be reviewed. The average ratings and tips on locations from students for other students are displayed, in a sense to make up for the lack of specific location recommendations. Additionally, researchers can analyze the collected review data in order to perhaps find out more about good learning environments. Users are also able to open an account and login on the website to save and view preferences, but as of yet, just one preference can be saved and viewed, and this feature is not much developed yet.

4.3 Programming Environment

The website was developed and tested on `www.000webhost.com` using phpMyAdmin for the database. The website was tested in Google Chrome (version 80.0.3987.87). At the time of submission of this thesis, the website will be available at the URL `http://lewizard.000webhostapp.com/index.html` and the source code will be available in the folder Learning Environment Wizard at the URL `https://github.com/bibilien/Learning-Environment-Wizard-Bachelor-thesis`.

The technologies used in the wizard are briefly presented below:

- **HTML:** HTML is used to display content on the website, such as text.
- **CSS:** CSS is used for design elements on the website, such as colors and padding.
- **JavaScript:** JavaScript is used to change the HTML content on the website, to retrieve data from HTML forms, and to send, request, and receive data from the databases via the PHP documents.
- **PHP:** PHP is used to connect the client and server. The PHP documents receive requests from JavaScript functions, send SQL queries to the databases to read or write data, and send responses such as data from a database back to the JavaScript functions.
- **SQL:** SQL is used to read, insert, and update entries in a database.
- **AJAX:** AJAX is a technology which allows JavaScript documents to asynchronously communicate with a PHP page, i.e., the website can be used as usual while requests are handled in the background. This technology was chosen because it allows for a smoother user experience with few page reloads (*Synchronous and asynchronous requests*).

Additionally, Bootstrap was used to simplify the process of designing the HTML pages.

4.4 User Management Roles

The phpMyAdmin account can access and edit all databases. Further, an admin account was opened on the wizard website where the review data can be downloaded as a CSV document.

4.5 Project Structure

The website consists of several HTML pages. The content an HTML page is managed through the according JavaScript document. The functions of this JavaScript document send or request data from the according PHP document. The PHP document then updates or reads entries from a database and sends an answer back to the JavaScript function which then changes the content of the HTML page. In total, there are three databases: one for locations containing general information such as address and opening hours, one containing the submitted reviews on locations, and one containing the registered users. An overview of documents and their relationships is given in Figure 4.1.

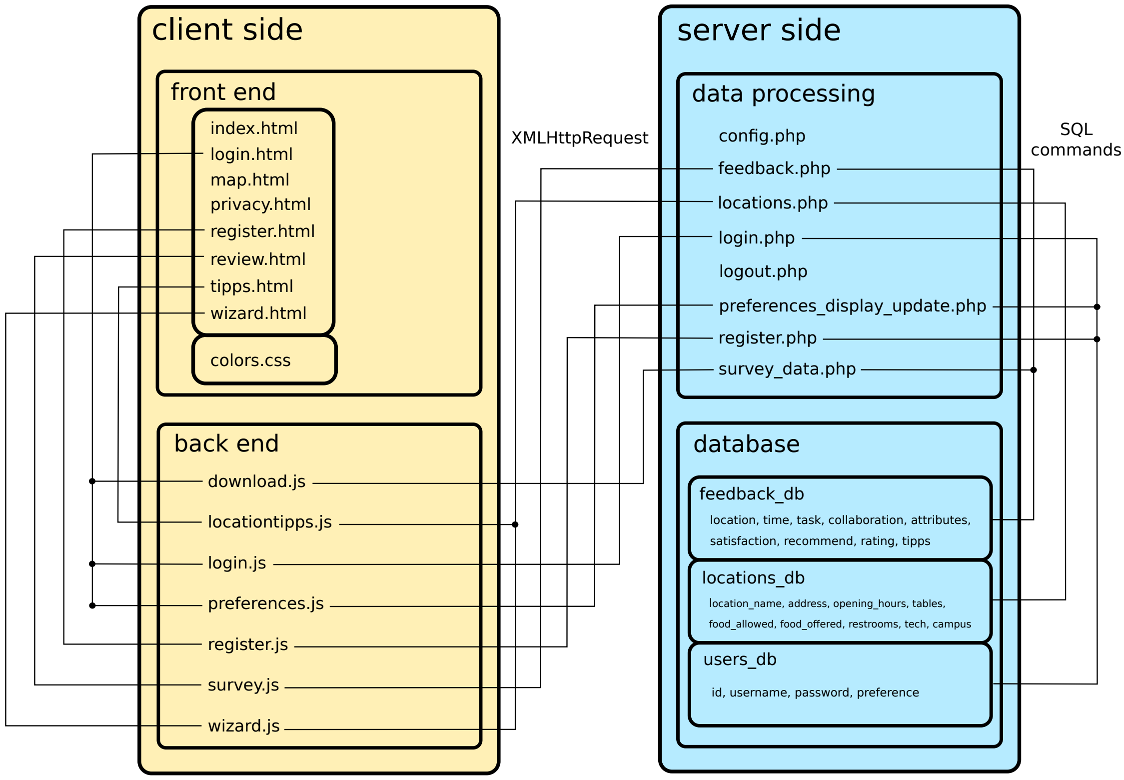

Figure 4.1: The project structure of the Learning Environment Wizard. In this figure, you can see all existing documents and how they relate to each other. Front end HTML documents call functions in the JavaScript documents in the back end, which then send requests to the server-side PHP documents via XMLHttpRequest. The PHP documents then read or write data in the databases via SQL commands and send an answer back to the client side.

4.6 Components

4.6.1 Wizard

The wizard guides the user through a series of questions. One question is displayed at a time, via CSS attributes, because the next question that will be displayed depends on the answer given on the previous question, so it is not possible to display all questions at once. This procedure is visualized in a flowchart in Figure 4.2. It shows for which answers which question is displayed next. For example, if a user states that he is not currently in Frankfurt, the wizard will skip the question asking him which campus is nearest to him.

At any time during this process, the user can go to the next and previous questions using two buttons located beneath the questions. This was done to increase user friendliness as users might accidentally answer a question incorrectly and would want to correct that answer. The alternative would have been for the user to start over and potentially answer many previously correctly answered questions again which might annoy the user and deter him from using the wizard again. All questions have a "keine Ahnung" answer option so as not to force the user to decide for an answer option he might feel is incorrect.

Once all questions have been answered, the wizard displays all questions and the given answers so that the user can check if he answered each item correctly. Otherwise he might receive an unsuitable result because he accidentally answered a question incorrectly, or he would have to go back to the very first question and then back to the last question to check if every answer is correct which would take a long time and, thus, is not user friendly.

After the answers have been checked and submitted by the user, the wizard calculates the results according to the students' framework. Eight different results with several possible result texts for each result are calculated. The formulas for each result text can be found in Tables 4.2 and 4.3. If no formula of a certain result is fulfilled, the result stays blank and is not displayed; this can happen when the wizard, and thus the framework, does not know what to recommend in that specific situation.

Once the results have been calculated, they are displayed. The results contain recommendations on how to adjust the environment or which location the learner should seek for an optimal learning environment. If the user stated which campus is nearest to him, the wizard also displays a table containing information on specific locations near that campus. Finally, at any time the user is given the option to restart the wizard with a button which reloads the page.

4.6.2 Review

On this page, users can evaluate a specific learning location by filling out and submitting a form. The user can rate the location on a five star scale, state whether he would recommend the location to other users and whether he was satisfied with his learning outcome, select negative attributes that he feels describe the location, and give tips to other students who want to study at that location. The tips feature was inspired by the Spacefinder website mentioned in paragraph 4.1. Additionally, the form asks the user at what time of day he visited the location, whether he worked on simple or complex tasks, and whether he worked with other students. At any time, he can start over by clicking a button which reloads the page.

The specific location is selected from a drop-down list. The reason why the user was not given the option to enter the location manually is that one would then have to go through the reviews manually to collect all reviews to one location since the users probably would use varying names for the same location, e.g., "ZB" or "Zentralbibliothek", and this would be a time-consuming process. However, a drop-down list has certain disadvantages as well, e.g., new locations have to be added manually and only locations that are currently in the list can be evaluated.

4.6.3 Locations Table

The locations table presents basic information on each specific location such as address, opening hours, whether it has desks, chairs, and restrooms, and other info, e.g., whether the location has computers or rooms for collaborative learning. Additionally, it presents the results of the reviews if reviews on that location have been submitted. These results include the average rating on a five star scale, the percentage of recommendations, as well as negative attributes that students used to describe the location. If any negative attributes were checked in a review, the attributes are displayed as a warning in a cell with a red background which differs from the usual white background in order to grab the user's attention.

4.6.4 Tips

The tips section presents general advice on learning environments from the students' framework as well as the locations table containing information on all locations in the locations database. Further, it lists all tips that students submitted in the reviews, grouped by location. Users can easily jump to the according tips section with a link in the table so they do not have to scroll through the list of tips to find the location that interests them.

4.6.5 Other Pages

The website allows users to open an account and to log in and out of their account. This feature is not very developed at this point. The only functionality of an account is to save and update a preference on learning environment. The website also includes a map page with an embedded Google map so that users can look up locations, and a privacy page with data protection regulations.

4.6.6 Usability

The user receives feedback on most actions; for example, after a review has been submitted, the user is informed on whether the review was successfully received or not, and after he has updated his preference, he receives a confirmation if the update was successful. If the login fails, the user is informed whether his password was incorrect or his username, and if a username is taken during the registration process, the user is informed. If a required field in the form is left empty or a required radio button is not checked, the user is informed before submission. The user is also given instructions, e.g., on the minimum password length and on the purpose of the review section. This can make the user feel secure as he knows exactly what requirements he has to fulfill and whether his requests were successfully executed.

The wizard is also user-friendly because it allows users to correct mistakes and to view all given answers before submitting them. Also, users are given the option to restart the wizard and the review process at any time. In the tips section, they do not have to scroll through the long list of tips, but they can directly jump to the tips of their location of interest by clicking on a link in the table.

4.7 Limitations

At this point, the website's features are very limited. A comprehensive discussion of how the website could be further developed will follow in the Evaluation and Outlook. In this section, I will focus on the most important limitations.

The greatest limitation is that it is currently possible for the wizard to generate contradictory results. For example, if a user states he is introverted and working on a creativity task, the wizard will, on the one hand, tell the learner to make sure that his environment is especially quiet, but on the other hand, it will recommend a location with a moderate noise level. Such a result might confuse users, but unfortunately, it is not avoidable at this point, because in these cases, it is unclear which recommendation takes priority over the other. For example, in the mentioned case it is unclear whether an introvert working on a creativity task will benefit from a moderate noise level or whether the learner should seek a quiet environment. Additionally, the meaning of the "Keine Ahnung" answer option for the results and the flowchart is somewhat unclear, e.g., if the user does not know whether he has any essential oils, the wizard assumes that he does not have any and it will not ask him whether he likes the scent of the essential oil, and if the user is unsure whether he is currently in Frankfurt, the wizard assumes that he is and asks him which campus is nearest; but these decisions might not be the most appropriate ways to handle this answer option. Further studies might be needed to clarify such remaining uncertainties.

Further, once a warning is displayed for a certain location in the table, it is never removed, unless the according attribute is deleted from the database. This means that even if a location changes for the better, users will see the warning and might avoid a perfectly fine location. Therefore, the warning feature should be refined. For example, one could check if there is a correlation between certain attributes and the time the user visited the location; perhaps a certain location is only, e.g., crowded or noisy in the morning, and then the warning could be displayed only in the morning but not in the afternoon. This would be more helpful to users who might otherwise avoid going to a good location and make other locations more crowded. Generally, one should also consider how to prevent situations in which many students go to a select few learning spaces due to their good ratings, making them more crowded and noisy. One could, for example, delete reviews after a set time, allowing ratings to become more dynamic; this way, as locations with high ratings become crowded, their ratings would become worse faster than if all reviews, including old ones, were used to calculate the average rating, and at the same time, locations with low ratings might receive higher ratings as fewer students study there and the location becomes less crowded and noisy. For the warnings, it would perhaps also be useful to display a warning only after a certain percentage, e.g., half of reviewers have selected that attribute, since these attributes are somewhat subjective and certain reviewers might have differing opinions from others, so that outliers can currently cause the table to display a warning even if most reviewers did not select the attribute in question, which again could lead to learners avoiding a good location and crowding other locations.

Similarly, users should perhaps be given the option to delete tips that they submitted on a certain location if they feel that the tip is no longer applicable, to ensure that the reviews are meaningful and up to date. However, this would probably require students to submit reviews while logged in, which could decrease the total amount of reviews and tips submitted and make the ratings and tips section less meaningful if the hassle of opening an account and logging in is not worth the submission of a review to the user. This problem could be solved by separating the submission of tips from the submission of reviews; however, while this may keep the number of reviews from decreasing, it might still decrease the amount of submitted tips due to the increased effort required to submit a tip.

Furthermore, certain functions are programmed depending on the exact questions that are currently being used, most importantly the function that calculates the result in the wizard and the functions that determine which question will be displayed next when the "Weiter" (next) or "Zurück" (back) buttons are pressed. This is a problem because it makes changes difficult when new questions are added, particularly when one wants those questions to appear before the questions that are currently used. In an ideal scenario, an admin would merely have to add the question and the position of the new question in the wizard and how the result is to be calculated, instead of having to change the actual code. A similar problem that has already been mentioned is the fact that only locations that are currently in the drop-down list can be evaluated, whereas new locations need to be added manually.

Generally, hardly any design elements have been added. At this point, the website looks rather bland. By adding some color and other design elements, one could make the website look more appealing. Perhaps there is also a better way of displaying the location specific information; although the table gives a somewhat clear overview, its size is very large, especially on smaller devices such as phones, and it might become confusing when more locations are added. Additionally, the fact that the confirmation which appears after the user has updated his preference does not fade away might be confusing to users, because when the user updates his preferences again, the confirmation does not reappear, it merely remains displayed until the user logs out. Although the user can easily check whether his preference has been saved by clicking on the button which displays his preference, the user might be unsure as to whether his preference was actually updated.

Finally, the preference feature is not very developed yet and of little use to students at this point. However, the website could be further developed so that the saved preferences are included in the wizard. This way, the wizard could, e.g., skip the questions on essential oils if the student saved in his preferences that the use of essential oils does not benefit him. Additionally, the preference feature could be used to help the learner become aware of bad habits, e.g., by asking him after a set time whether he still thinks that his preference improves his learning outcome.

4.8 Summary

In this chapter, I presented the basic structure and functionality of the Learning Environment Wizard. The website's main features are the wizard which makes recommendations on learning environments, the review feature which lets users evaluate a specific location, the tips section which displays information, ratings, and student tips on specific locations, as well as the preference feature which lets students save preferences on learning environments. The website's front end primarily consists of HTML pages whose content is managed by JavaScript functions which send requests to PHP documents which, then, send SQL commands to the databases before sending an answer back to the JavaScript functions. The website displays instructions and confirmations and lets users correct mistakes in order to ensure good usability. The most important limitations of this website include the sometimes contradictory results of the wizard, and the handling of warnings. Overall, however, the website is well-functioning and the usability is assumed to be good. Whether students find the usability good as well will be revealed in the evaluation.

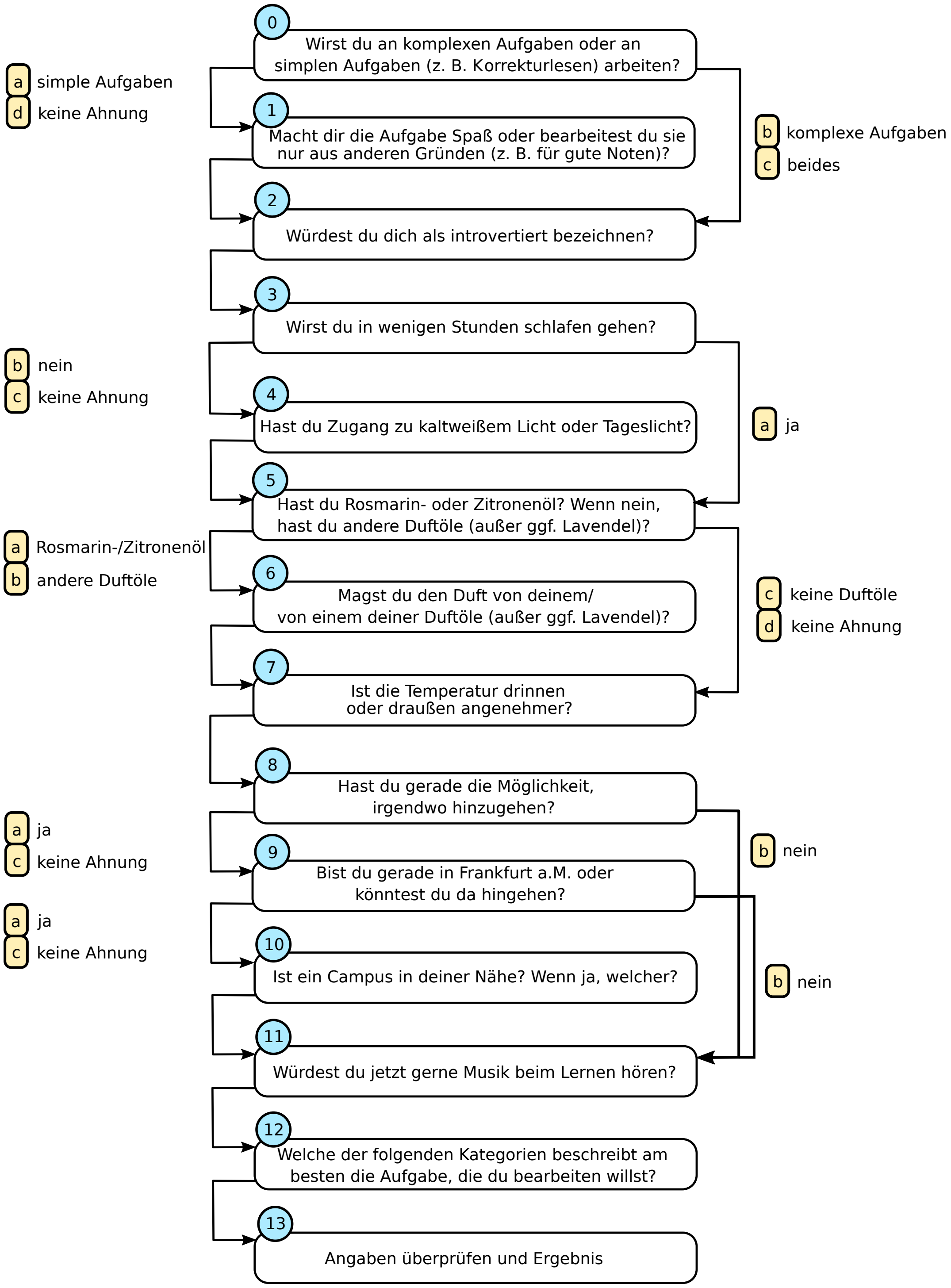

Figure 4.2: This flowchart shows how the wizard in the Learning Environment Wizard chooses the next question based on the given answers. The answer option index, a letter, is given in the rectangular boxes, and the according answer text is to the right of it. The number in the circles contains the question index. If there are answers next to an arrow, it means that for these answers the wizard goes to the question to which the arrow is pointing; else, the wizard goes to the question to which the arrow is pointing, regardless of the given answer.

Aspect	Questions	Result No.	Formula	Situation	Result
social presence	0, 1	0	0a or 0d	The learner is working on simple tasks or does not know the task's complexity, and he is intrinsically motivated.	"Lerne alleine."
			0b or 1b or 1c	The learner is working on complex tasks; or he is working on easy tasks or on tasks of unknown complexity, and not intrinsically motivated.	"Lerne zusammen mit anderen Studenten. Stellt sicher, dass ihr euch gut hören könnt. Wenn es in eurem Raum kalt ist, wie wäre es damit, eure Hände an einer heißen Tasse Kaffee oder Tee zu wärmen?"
			0c	The learner is working on simple as well as complex tasks.	"Bearbeite die einfachen Aufgaben alleine. Die komplexen Aufgaben kannst du mit anderen Studenten bearbeiten. Stellt sicher, dass ihr euch gut hören könnt. Wenn es in eurem Raum kalt ist, wie wäre es damit, eure Hände an einer heißen Tasse Kaffee oder Tee zu wärmen?"
noise	2	1	2a	The learner perceives himself as an introvert.	"Achte besonders darauf, dass deine Lernumgebung still ist."
light	3, 4	2	3a	The learner has to go to sleep in a few hours.	"Lerne möglichst mit warmweißen Licht und minimiere ggf. Tageslicht. Positioniere dich so, dass du nicht geblendet wirst."
			4a	The learner does not have to go to sleep soon or does not know his bedtime, and he has access to cold white light or daylight.	"Lerne mit Tageslicht oder alternativ kaltweißem Licht. Positioniere dich so, dass du nicht geblendet wirst."
			4b or 4c	The learner does not have to go to sleep soon or does not know his bedtime, and he does not have or does not know if he has access to cold white light or daylight.	"Lerne mit möglichst hellem Licht, solange es für deine Augen angenehm ist. Positioniere dich so, dass du nicht geblendet wirst."
smell	5, 6	3	5a and not 6b	The learner owns lemon and/or rosemary essential oil and enjoys its scent or is unsure if he enjoys its scent.	"Benutze das Rosmarin- oder Zitronenöl (z. B. auf einem Duftstein), solange dich der Duft nicht ablenkt."
			5b and not 6b	The learner owns other essential oils besides lavender oil and enjoys its scent or is unsure if he enjoys its scent.	"Benutze (z. B. auf einem Duftstein) dein/eins deiner Duftöle, das du magst, solange dich der Duft nicht ablenkt. Benutze kein Lavendelöl."
temperature, air quality	7, 8	4	7a or 8b	The temperature is more pleasant inside than outside or the learner is not able to leave his current location.	"Lerne drinnen. Denk daran, regelmäßig zu lüften, v. a. bei Kopfweh, Müdigkeit oder Übelkeit."
			7b and not 8b	The temperature is more pleasant outside than inside and the learner is able to or unsure if he can leave his current location.	"Lerne draußen, solange das Wetter angenehm ist. Denk daran, deine Kleidung an die Temperaturen anzupassen und nicht in der direkten Sonne zu sitzen."
			7c and not 8b	The learner does not know whether the temperature is more pleasant inside or outside, and he is able to or unsure if he can leave his current location.	"Wenn du willst, kannst du rausgehen und bei schönem Wetter dort lernen. Wenn du drinnen bleibst, denk daran, regelmäßig zu lüften, v. a. bei Kopfweh, Müdigkeit oder Übelkeit."

Table 4.2: This table shows how the wizard calculates each of eight result texts based on a formula of given answers abbreviated to the question index and answer option index.

Aspect	Questions	Result No.	Formula	Situation	Result
none (location)	10	5	10a	The nearest campus to the learner is Westend.	"Lerne am Campus Westend."
			10b	The nearest campus to the learner is Bockenheim.	"Lerne am Campus Bockenheim."
			10c	The nearest campus to the learner is Riedberg.	"Lerne am Campus Riedberg."
			10d	The nearest campus to the learner is Niederrad.	"Lerne am Campus Niederrad."
			10e	The nearest campus to the learner is Ginnheim.	"Lerne am Campus Ginnheim."
			10f or 10g	The learner does not know which campus is nearest to him.	"Lerne in einer Bibliothek, einem Buchladen oder einem ruhigen Cafe."
temperature, air quality, light	8, 9, result 4	5	not 9b and not 8b and (result 4 != "Lerne drinnen. Denk daran, regelmäßig zu lüften, v. a. bei Kopfweh, Müdigkeit oder Übelkeit." and result 4 != „“)	The learner is in or is unsure if he is in Frankfurt and he is able to or unsure if he can leave his current location. Additionally, result 4 was neither blank nor did it suggest that the learner stays inside.	(concatenated) "Du könntest auch in den Palmengarten oder Grüneburgpark gehen."
noise	2, 11	6	11a and 2a	The learner perceives himself as an introvert and he would like to listen to music while studying.	"Auch wenn du beim Lernen gerne Musik hörst, wäre es wahrscheinlich besser für dich, keine Musik zu hören. Wenn du trotzdem Musik hören willst, dann nur instrumentale Musik ohne Liedtext."
			11a and not 2a	The learner does not perceive himself as an introvert and he would like to listen to music while studying.	"Wenn du Musik hören willst, dann nur instrumentale Musik ohne Liedtext."
			11b or 11c	The learner would not like to or is unsure if he would like to listen to music while studying.	"Höre keine Musik beim Lernen."
noise, color	12	7	12a or 0a	The learner's task is proofreading or another simple task.	"Durchgehende Geräusche werden dich nicht viel stören. Du kannst also ruhig in ein Cafe oder in den Park gehen, wenn du willst."
			12b	The learner's task is a creativity task.	"Gehe am besten irgendwo hin, wo du einen mittelstarken Geräuschpegel hast, z. B. in ein Cafe oder in den Park. Wenn du am PC arbeitest, schalte darauf einen blauen Hintergrund ein."
			12c or 12e	The learner's task is reading or an auditory task.	"Achte besonders auf eine leise Umgebung."
			12d	The learner's task is a memorization task.	"Achte besonders auf eine leise Umgebung. Wenn du am PC arbeitest, schalte darauf einen roten Hintergrund ein."

Table 4.3: *(Table 4.2 cont.)* This table shows how the wizard calculates results based on formulas.

5 Evaluation

This chapter presents the evaluation of the Learning Environment Wizard. First I will present a user guide on how to use the various features of the website. Then I will present the study's results, and finally, I will discuss the results and the study's limitations. At the time of submission of this thesis, the survey results will be available in the folder "survey" at the URL `https://github.com/bibilien/Learning-Environment-Wizard-Bachelor-thesis`.

5.1 User Guide

In the wizard, the user is guided through the flowchart with a series of questions that the user answers. The next question depends on the user's answer of the previous question(s). Once all questions have been answered, an overview of the given answers is displayed so the user can check if every answer is correct. If this is the case, the result will be displayed.

The survey is straightforward: the user answers the questions and then submits the survey.

In the tips section, the user can jump back and forth between the table with the ratings and information on locations and the location-specific tips of each location.

To register, the user simply enters his information, and if the registration was successful, he can log in. When logged in, the user can enter his new preference and click the "Speichern" button to save it and, after clicking the "Präferenzen anzeigen" button, the updated preference is displayed. If the admin logs in, they can choose between a comma and a semicolon as a separator symbol for the CSV document and then download the review data.

5.2 Goal

The goal of this study is mainly to receive basic feedback on the wizard's usability and to find out which other features students would appreciate in such an application since the wizard, at this point, is merely a prototype and can be further developed in many ways. This survey will help future developers determine which additional features should be prioritized over others and which currently implemented features might be confusing or hard to use.

5.3 Sample

The website was evaluated by 13 people. Of these participants, about 62% (n = 8) were females and 23% (n = 3) were male (15% other or not specified). The mean age was 22.85

years (SD = 2.48), ranging from 20 to 30 years. Most participants were aiming for a Bachelor's degree (n = 7) or a Master's degree (n = 5). The distribution of Goethe University students (n = 6) and students from other universities (n = 7) was approximately equal, and the average semester was 6.62 (SD = 4.09), ranging from 1 to 16. Most participants studied a social science subject (n = 8), followed by STEM students (n = 3), as well as one humanities student and one student in teacher training. Social science subjects included pedagogy, economics, newer philology, psychology, and linguistics, whereas STEM included computer science and biology, and humanities included cultural science.

5.4 Instrument

The survey used for the evaluation is the System Usability Scale (SUS), a valid and reliable tool for evaluating usability consisting of ten items in English language that are rated on a 5-point Likert scale ("The Factor Structure of the System Usability Scale"). Since the website was developed for German-speaking users, the German version of the SUS was used (*System Usability Scale - jetzt auch auf Deutsch.*). The SUS part of the survey was used to evaluate the website as a whole, so three more items specifically on the wizard were added. An item which asked participants for suggestions for further developments of the website and a few socio-demographic items were added as well. The survey was conducted online at `www.soscisurvey.de`. The link to the wizard was provided in the survey. The survey was active for five days. The link to the survey was distributed to fellow students and they were asked to forward the link to their own fellow students. The participation was voluntary and the participants received no compensation.

At the beginning of the online survey, participants were asked to acquaint themselves with the website. Each participant could freely choose for how long he tested the website and the time was neither measured nor was a minimum amount of time recommended. Then, the participants completed a survey questionnaire (see Appendix 1: Survey Questions).

5.5 Data Analysis

Since the goal of this survey is to simply receive basic feedback and suggestions, no statistical tests were conducted. The means, medians, standard deviations, and ranges of items were merely compared. For the analysis of the SUS results, the score contributions are compared. The original results vary in regards to which end of the scale is considered best, whereas the score contributions are standardized to a range of 0 to 4 with 4 being the best rating for all items, resulting in easier comparability.

5.6 Results

5.6.1 SUS Score

The results to the SUS questions can be found in Table 5.1 and as a diagram in Figure 5.1. The score contributions can be found in Figure 5.2. The SUS score was calculated according

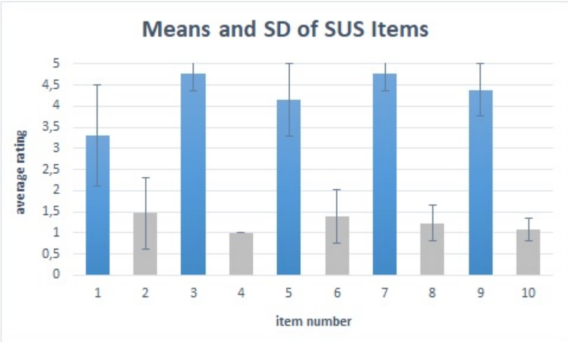

Figure 5.1: The means and standard deviations of the SUS items. Blue (dark) items have a best possible rating of 5 and a worst possible rating of 1, and vice versa for gray (light) items.

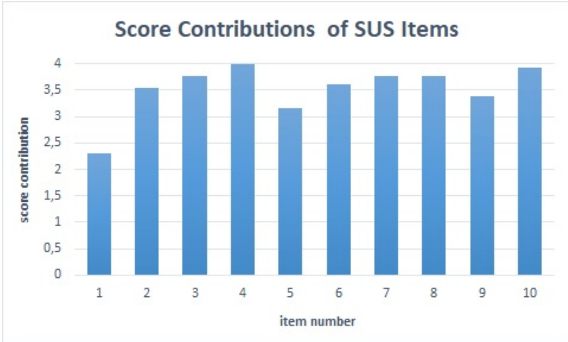

Figure 5.2: The score contributions of the SUS items. Each item has a range of 0 to 4 with 4 being the best possible rating.

to Brooke (1996). The survey results yielded a score of 88.08 out of 100. The average SUS score for websites seems to be 70.1 or 62.1 ("The Factor Structure of the System Usability Scale"), so the SUS score for this website can be considered above average.

The item with the lowest ratings was item 1 (*"Ich denke, dass ich das System gerne häufig benutzen würde."*) with a score contribution of 2.3. This item also had the highest standard deviation (SD = 1.2) and the largest range (range = 1 to 5), ranging over the whole scale. The item with the highest rating was item 4 (*"Ich glaube, ich würde die Hilfe einer technisch versierten Person benötigen, um das System benutzen zu können."*) with a score contribution of 4 which is the highest possible rating. With a standard deviation of zero, this item also had the lowest standard deviation of all items and the smallest range (range = 1 to 1). Item 10 (*"Ich musste eine Menge lernen, bevor ich anfangen konnte das System zu verwenden."*), too, had a very high – the second highest – rating with a score contribution of 3.92 and a standard deviation of just 0.27.

	SUS1	SUS2	SUS3	SUS4	SUS5	SUS6	SUS7	SUS8	SUS9	SUS10
mean	3.31	1.46	4.77	1	4.15	1.38	4.77	1.23	4.38	1.08
median	4	1	5	1	4	1	5	1	4	1
SD	1.2	0.84	0.42	0	0.86	0.62	0.42	0.42	0.62	0.27
range (min - max)	1 - 5	1 - 4	4 - 5	1 - 1	3 - 5	1 - 3	4 - 5	1 - 2	3 - 5	1 - 2
score contri-bution	2.31	3.54	3.77	4	3.15	3.62	3.77	3.77	3.38	3.92

Table 5.1: Results of the SUS questions, rounded to two decimal places. For gray columns, the best possible rating is 5 and the worst possible rating is 1, and vice versa for the white columns. The bottom row (gray) contains the score contributions, i.e., the standardized values ranging from 0 to 4 with 4 being the best possible rating for all questions.

Figure 5.3: The means and standard deviations of the three items on the wizard. The best possible rating is 5 and the worst rating is 1 for all questions.

5.6.2 Wizard Questions

The results to the three wizard questions can be found in Table 5.2 and as a diagram in Figure 5.3. The item with the highest rating was the second one (*"Die Anweisungen in der grünen Box waren leicht verständlich."*) with a median of 4.92, the lowest standard deviation (SD = 0.27) and the smallest range (range = 4 to 5). The item with the lowest rating with a mean of 3.54 was the third item (*"Das Ergebnis des Wizards war hilfreich."*) which also had the highest standard deviation (SD = 1.08) and the largest range encompassing the whole scale (range = 1 to 5).

	Were the questions easily understandable?	**Were the instructions easily understandable?**	**Were the results helpful?**
mean	4.38	4.92	3.54
median	5	5	4
SD	0.92	0.27	1.08
range (min - max)	2 - 5	4 - 5	1 - 5

Table 5.2: Results of the wizard questions, rounded to two decimal places. The best possible answer is 5 and the worst answer is 1 for all questions.

5.6.3 Suggestions from Participants

Three comments were received in total. The first comment pointed out that another part of an optimal learning environment is sitting at a desk since it gives a student a better overview over the learning material, makes a student sit upright which is more comfortable in the long term, and makes the student stay awake since they are sitting.

The second comment called attention to the fact that many libraries have several very differently equipped rooms and that it would be practical if the locations table on the website listed these features separately for each room.

The third comment had many suggestions, especially for the locations table, for example: being able to filter locations according to type, putting the locations in an alphabetical order, a slightly narrower table, and putting the link to a location's tips in the location name instead of having a "Zu den Tipps!" column of links. Additionally, the participant found the word "Warnungen" too harsh and said that it might make people biased, and suggested "häufige Kritikpunkte" instead. The participant found the word "Tipps" misleading as well and seemed to suggest the word "Kommentare" instead and a separate page for those comments. Further, the participant found the percentage of recommendations and the average rating redundant and suggested removing one of those columns.

The third comment included suggestions for the rest of the website as well, such as changing the navigation bar so that it shows on which page the user currently is, perhaps combining the login and registration page, and changing the title "Bewertung" to "Bewertung abgeben" to prevent users from thinking that they can read reviews on that page. Additionally, the participant found the relationship between the learning environment and the name "Wizard" unclear and suggested rewriting the questions of the wizard: instead of the question "Würdest du dich als introvertiert bezeichnen?", they suggested "[I]st dir die Gesellschaft von Leuten beim Lernen von Bedeutung/un-angenehm[?]", and they did not see the meaning of the question on essential oils. Apart from these criticisms, however, the participant found the website very nice and said that they would definitely use it.

5.7 Discussion

Generally, the results can be considered quite good: none of the means are below 50% of the highest possible rating, i.e., no score contribution is below 2 and no mean of the wizard items is below 3, and consequently, the SUS score is well above average.

The two items with the lowest ratings are SUS item 1 (*"Ich denke, dass ich das System gerne häufig benutzen würde."*) and wizard item 3 (*"Das Ergebnis des Wizards war hilfreich."*) which each also had the lowest standard deviation among the SUS items and the wizard items, respectively, and the largest ranges of 1 to 5, encompassing the whole range. This indicates that, although one cannot say that participants as a whole rated these items low on the scale since the means were in the higher half of the scale, the items did cause most disagreement among participants and extreme differences in ratings. The distribution of ratings on these items can be found in Figures 5.4 and 5.5.

Wizard item 3 (*"Das Ergebnis des Wizards war hilfreich."*) generally received quite good ratings, with eight participants rating it 4 or 5, indicating that most participants found the wizard's results helpful. Just two participants rated the item below 50% and did not find the wizard's results helpful. Unfortunately, no participant used the comment section to comment specifically on the results of the wizard, so one can only guess as to what the reason for the comparably low rating on this item might be: perhaps some participants found the results too obvious, for example, because they already follow most of the recommendations such as making sure that students can hear each other during collaborative learning or because the result recommends doing something that a student has no choice in anyway, such as using no essential oils when the user has none or staying inside when the user stated that he cannot leave his current location; or perhaps the participants found the recommendations too unspecific and hard to apply in reality, for example, by having to assess the complexity of a task, the color temperature of light, or the task type of a task whose task type is either hard to assess or which consists of multiple task types. If this is the case, it might become necessary to think of ways of supporting users in assessing those things, e.g., by giving examples or by offering more specific results for tasks with multiple task types.

SUS item 1 (*"Ich denke, dass ich das System gerne häufig benutzen würde."*) has a more irregular distribution, but generally, more participants rated the item above 50% (n = 7) than below (n = 4), showing that more participants would use than not use the system often. The reason why this item was rated comparably low might be explained partly with the low rating on wizard item 3, i.e., the wizard's results being unhelpful according to some participants. Although the SUS items refer to the whole website, the wizard and the tips section are the two major features on the website, so a negative opinion of one of those two major features can definitely be expected to have a negative impact on a participant's desire to often use the website as well. This view is supported by the fact that three out of four participants who rated SUS item 1 below 50%, i.e., 1 or 2, rated wizard item 3 at or below 50% as well; conversely, nine out of eleven participants who had rated wizard item 3 at or above 50% also rated SUS item 1 at or above 50% (see Figure 5.6). The other major feature, the tips section, was not separately evaluated, but some participants suggested several ways of how this section could be improved and become more helpful to users, for example, by listing the features of different rooms of a library separately. It is possible that other participants might have had similar thoughts on the tips section, despite not leaving any comments on that topic, and that this also partly explains the comparably low rating on SUS item 1. Since the website is ultimately useless if no one or just very few students use it, this feedback and these suggestions should be taken seriously, and more students should be asked for an evaluation so that the reasons for the different views on the website and on the wizard's helpfulness can be determined. Finally, some participants might have rated SUS item 1 low because they simply never go anywhere to study. Although the wizard does give recommendations for users studying at home as well, some participants might not feel that there is much to change in their home learning environment and, thus, that the wizard is useless to them. Perhaps this could be counteracted by pointing out on the website that the wizard also gives recommendations for studying at home and that it is possible to improve one's learning environment even if one studies at home.

The two items with the highest ratings were SUS item 4 (*"Ich glaube, ich würde die Hilfe einer technisch versierten Person benötigen, um das System benutzen zu können."*, score contribution = 4, SD = 0, range = 1 to 1) and wizard item 2 (*"Die Anweisungen in der grünen Box waren leicht verständlich."*, mean = 4.92, SD = 0.27, range = 4 to 5). The second highest SUS item was item 10 (*"Ich musste eine Menge lernen, bevor ich anfangen konnte das System zu verwenden."*, score contribution = 3.92, SD = 0.27, range = 1 to 2). The two highest items also had the lowest standard deviation among the SUS items and the wizard items, as well as the smallest ranges, indicating general agreement on the items. All participants found the website easy to use without help from another person, and most found the wizard instructions clear and did not feel they needed any preknowledge to use the website. Thus, the website generally seems to be easy to use.

The SUS has been shown to deliver reliable results even for a sample size of just twelve participants (Tullis and Stetson 2004). Since this survey had 13 participants, the results can be considered reliable. Additionally, the group of participants was quite diverse in gender, age, intended degree, university, and somewhat in faculty, making the results reflective of a large part of students. Considering the above-average SUS score, the website generally seems to have good usability, whereas its main problems seem to lie more in its lack of helpfulness to some users.

Most of the participants' suggestions are reasonable and might even increase the website's usefulness. One participant suggested rewriting some of the wizard's questions, specifically the question on introversion; however, since the study that this recommendation is based on examined introversion in general, and not introversion during studying, it might be wrong to change the question to the suggested question. However, one could rephrase the question to something similar, e.g., to "Ist dir die Gesellschaft anderer Leute unangenehm?", as this might be easier for users to answer than the original question. The participant also did not see the relevance of the question on essential oils, adding that they personally do not use any. Although it is unknown whether other participants shared this sentiment, it might be possible that the use of essential oils is not very common and, if this is the case, that the thought of scents affecting learning is perhaps seen as unrealistic. This could then contribute to the feeling that this question is irrelevant in the wizard. Perhaps this issue could be resolved by rephrasing the result texts so that they sound less like a strict recommendation and more like an encouragement to try out new methods such as essential oils even if the user does not believe that they will help them, as has been done with the suggestion to warm one's hands on a hot cup of coffee when learning collaboratively.

5.8 Limitations

Although the study did have participants from a quite broad range of faculties, the amount was limited; for example, we had no medicine or law students among the participants. While this was to be expected in such a small study, it could be a problem: students from other faculties not represented in this survey might desire other features than the current participants. For example, they might have faculty-specific learning spaces that they would like to see included so they can evaluate them. Further, solely the wizard was evaluated with a separate set of items; the other major part of the website, the tips section, was not. This created some uncertainty in interpreting the results on SUS item 1.

5.9 Summary

In this chapter, I presented the results of a small student survey on the usability and usefulness of the Learning Environment Wizard. The results show that the website's usability is generally good. However, some participants had no or little desire to use the website or they found the wizard's results of no or little helpfulness; there also seems to be a relationship between those two groups of participants. Possible reasons might include the wizard results being too obvious

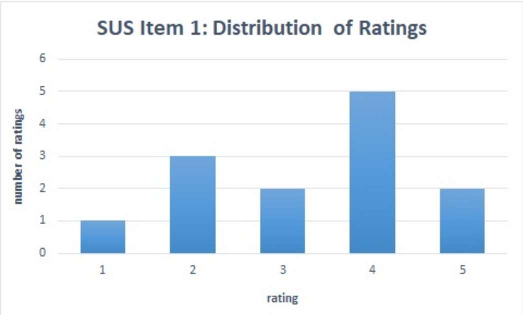

Figure 5.4: The distribution of ratings on SUS item 1 with 5 being the best possible answer and 1 being the worst possible answer.

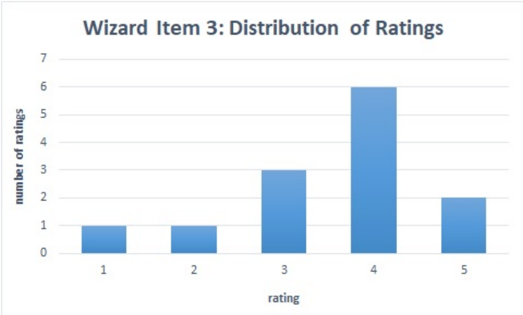

Figure 5.5: The distribution of ratings on wizard item 3 with 5 being the best possible answer and 1 being the worst possible answer.

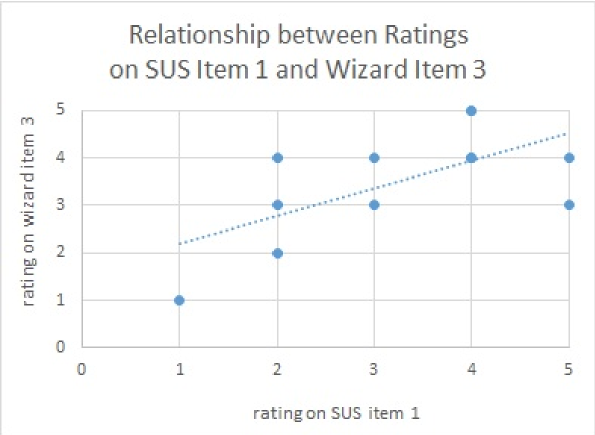

Figure 5.6: The relationship between the ratings on SUS item 1 and wizard item 3. There are less dots than the number of participants due to dot (4|4) being tripled and dot (4|5) being doubled.

or hard to apply in reality. Some participants also made suggestions for improving the website, specifically the tips section. Most of the participants' suggestions would probably increase the usefulness of the website and should therefore be implemented.

6 Outlook

This chapter presents the conclusion of this thesis. First, I will summarize the previous chapters. Finally, I will present the possible future works and suggestions that were not a part of this study.

6.1 Conclusion

In this thesis, we have learned that the environment, specifically noise, light, color, smell, space, temperature, air quality, and social presence affect our mood, health, behavior, and cognition in both, positive and negative ways. However, we are not at the environment's mercy: there are, fortunately, many ways to adjust the environments to our needs and to minimize its negative effects as well as gain advantages from positive effects. A guide on how to do this was formulated in the two frameworks for students and higher teaching institutions.

The Learning Environment Wizard presents a practical implementation of the students' framework. Despite its limitations, such as the sometimes contradictory results and the handling of warnings, it is a well-functioning website and its usability is good, as shown by the above-average SUS score from the survey. The survey results further revealed that the website's main problems lie in the lack of usefulness to some users. This issue might be resolved by implementing some of the participants' suggestions for further developments.

6.2 Outlook

The environment and its effects on humans is a great topic with many interesting aspects. Although we examined many of them in this thesis, there is a lot more to investigate. Therefore, to close this thesis, I want to present an outlook for further research and further development of the Learning Environment Wizard.

6.2.1 Further research

The main problem of the literature review was the unclear definition of learning. This resulted in many studies examining the effects of the environment on differing task types. To be able to compare studies and their results, it will be necessary for them to use the same types of cognitive assessment. Thus, it should be investigated which areas make up cognition and how they can be assessed. One possible solution might be the dual-task approach examined by

Brunken, Plass, and Leutner (2003) who write that it can be used to "measure cognitive load without relying on subjective self-reported data, indirect performance measures, or behavioral or physiological measures that have only an indirect causal link to cognitive load and that may, therefore, be affected by other factors" (p. 59). It should then be clarified what task types college students usually perform and how they relate to the task types used for cognitive assessment. Only then can the framework make reliable task-type specific recommendations for college students. Since effects will also become more comparable between environmental aspects, the wizard will then be able to prioritize certain recommendations over others and to avoid giving contradictory results which was a problem identified in Chapter 4. Such a prioritization was attempted in the discussion of the literature review and it was concluded that a quiet environment is probably most important; whether this assessment is true can only be determined once effects between environmental aspects become comparable.

Such an investigation also requires a more consistent definition of certain other aspects; for example, crowding should consistently be defined as either social density or spatial density, and for air quality, it might be necessary to split up the aspect into subaspects such as CO_2 level and ventilation rate so that these different factors can be examined separately and not be mixed together.

Generally, more realizations of aspects should be examined. For noise, different types of music could be examined. For color, combinations could be examined instead of just monochromatic offices, as well as the effects of different patterns and of color on other objects such as furniture or paper. The effect of images, "meaningful color" in a sense, could be examined as well; for example, biophilic design, e.g., direct contact to nature or images of nature (Spivack, Askay, and Rogelberg 2010) might have a positive effect on learning. For smell, the effects of more common smells such as the smell of food could be examined. For space, augmented and virtual reality could be used to easily try out different room set-ups which might be especially useful in the process of designing new learning spaces, and one could examine whether some form of blinders, folding screens, or curtains can mitigate negative effects of crowding in large learning spaces. For air quality, other indoor pollutants, e.g., dust in carpet flooring could be examined. For collaborative learning, one could examine whether there are certain criteria such as preferred learning style that determine which students will efficiently study together, as well as which students are prone to social loafing and how this can be prevented. There are also additional environmental aspects that were not examined at all in this thesis, such as building condition and also seating arrangements which might be of importance to learning (Merriënboer et al. 2017), as also suggested by one participant of the survey.

Finally, the relationship between the environment and internal aspects such as sleepiness, hunger, and emotion could be examined. For example, a hungry person might be more easily distracted by the scent of food than a non-hungry person, and hearing someone scream might make a person feel scared, whereas hearing people cheer might make a person curious. For certain environmental aspects, this relationship has already been examined, for example the relationship between sleepiness and light, and the relationship between certain personality traits and social presence. There might even be internal ways of mitigating negative environmental effects, for example by having an internal locus of control (Wolinsky et al. 2009). Other factors of interest for further research might be personal control (Ulrich et al. 2018), privacy, and territoriality (Spivack, Askay, and Rogelberg 2010).

6.2.2 The Learning Environment Wizard

The main limitations of the Learning Environment Wizard as discussed in Chapter 4 are the sometimes contradictory results of the wizard and the handling of warnings. The former issue should be settled as the problems discussed in the previous section are resolved, and the new findings could additionally be used to refine the rating system so that more detrimental attributes weigh more than less detrimental ones. The handling of warnings, on the other hand, will take more careful considerations as to what the best approach is. Several different strategies could also be tested in simulations or small pilot projects.

Other areas which need further development are the lack of design and colors, and the preference section. The preferences in particular could be used in many ways; for example, they could be incorporated in the wizard or used to raise awareness for unhelpful preferences in the user or to encourage him to try out new learning environments. Additionally, students should be enabled to add or suggest new locations, and to delete tips.

One could also add a feature which allows students to find other students for learning collaboratively by matching them based on location. Then, if the wizard suggests collaborative learning, it could automatically suggest study partners who are also currently using the wizard and are near the same campus.

It might also be useful to add regular push notifications that remind students to open the windows to let fresh air in if they are studying indoors. This could be used for internal factors as well; for example, if studies find that being hydrated is beneficial for learning, the push notifications could also remind the user to drink water.

Apart from that, the survey's results in Chapter 5 showed that the website could be improved in several ways. For the tips section, different library rooms could be listed separately in the table as they might differ in available equipment, and locations could be filtered by type and listed in an alphabetical order. The navigation bar could be adjusted so that it shows on which page the user currently is. Some titles should perhaps be changed, such as "Warnungen" to "häufige Kritikpunkte". Some of the wizard results could also be rephrased to sound more encouraging. Finally, it might be beneficial to give examples of different task types, task complexity levels, or light temperatures to users in the wizard so they can better assess them, and to point out that the wizard gives recommendations to users studying at home as well.

6.2.3 Other kinds of support for students

The Learning Environment Wizard is not the only way of helping students in regards to learning environments. For example, a room color could easily be changed by wearing colored glasses; noise cancelling headphones or earplugs might help students in noisy environments; colorful paper or ink in exams might increase students' cognitive performance; libraries could use infrared devices to display the number of free desks in real time, as the UCL Go! app mentioned in Chapter 4 does. Finally, further research might also yield new approaches for supporting students in improving their learning environment.

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Appendices

Appendix 1: Survey Questions

Seite 01

Evaluation des Learning Environment Wizards

Liebe Teilnehmerin, lieber Teilnehmer,

vielen Dank, dass Sie sich die Zeit für diese Umfrage nehmen! Durch Ihre Teilnahme erfahren wir mehr über Ihre Meinung zu dem Learning Environment Wizard. Dies ist eine Website, die im Rahmen einer Bachelorarbeit für Studierende wie Sie entwickelt wurde, um Euch beim Finden einer optimalen Lernumgebung zu unterstützen. Außerdem können Studierende dort Lernorte (bis jetzt nur Bibliotheken) bewerten.

Worum geht es?

Diese Umfrage bietet Ihnen die Möglichkeit, den Learning Environment Wizard zu evaluieren. Am Ende der Umfrage können Sie Kommentare zur Website sowie Vorschläge für weitere Entwicklungen abgeben. Die Website ist erreichbar unter der folgenden URL:

http://lewizard.000webhostapp.com/ (Website wird in neuem Tab geöffnet)

Bitte öffnen Sie den Link und machen Sie sich kurz mit der Website vertraut, bevor Sie mit der Umfrage beginnen.

Was passiert mit meinen Daten?

Die Auswertung Ihrer Antworten erfolgt anonymisiert und vertraulich. Sämtliche Daten werden ausschließlich zu wissenschaftlichen Zwecken erhoben und nicht an Dritte weitergegeben.

Gibt es etwas bei der Teilnahme zu beachten?

Die Teilnahme ist freiwillig. Sie richtet sich primär an Studierende der Goethe-Universität Frankfurt a. M., aber auch an andere Studierende und dauert **etwa 5 Minuten**. Sie können die Umfrage jederzeit ohne Angabe von Gründen abbrechen; dadurch entstehen Ihnen keinerlei Nachteile.

Bei Fragen und Anmerkungen wenden Sie sich bitte an Bianca Lien unter **s0580779@stud.uni-frankfurt.de**.

Vielen Dank für Ihre Unterstützung!

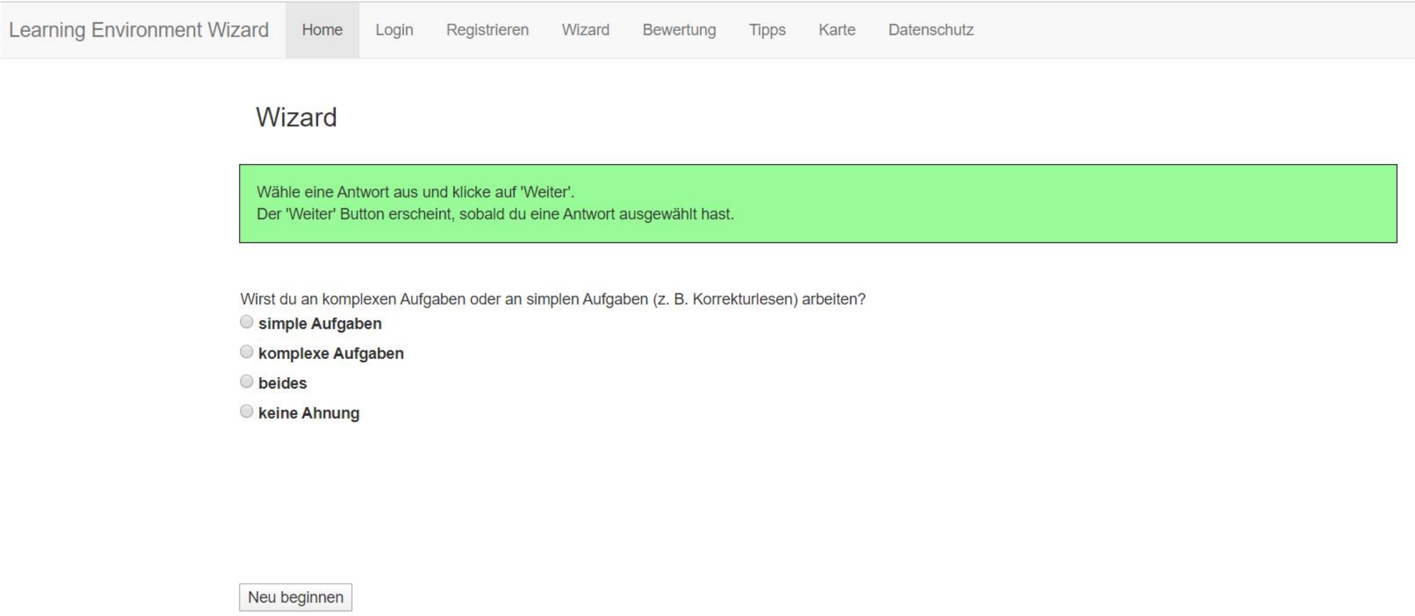
Seite 02

Im Folgenden werden Sie die Website als Ganzes evaluieren.
Hierfür werden Ihnen zehn Aussagen präsentiert. Bitte stufen Sie für jede Aussage auf der rechts befindlichen Skala ein, wie sehr Sie der jeweiligen Aussage zustimmen.
Wenn Sie der Aussage überhaupt nicht zustimmen, wählen Sie bitte die linkeste Option. Wenn Sie der Aussage voll zustimmen, wählen Sie bitte die rechteste Option.

Bitte stufen Sie ein, wie sehr Sie der jeweiligen Aussage zustimmen.

1. Ich denke, dass ich das System gerne häufig benutzen würde.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu
2. Ich fand das System unnötig komplex.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu
3. Ich fand das System einfach zu benutzen.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu
4. Ich glaube, ich würde die Hilfe einer technisch versierten Person benötigen, um das System benutzen zu können.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu
5. Ich fand, die verschiedenen Funktionen in diesem System waren gut integriert.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu
6. Ich denke, das System enthielt zu viele Inkonsistenzen.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu
7. Ich kann mir vorstellen, dass die meisten Menschen den Umgang mit diesem System sehr schnell lernen.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu
8. Ich fand das System sehr umständlich zu nutzen.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu
9. Ich fühlte mich bei der Benutzung des Systems sehr sicher.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu
10. Ich musste eine Menge lernen, bevor ich anfangen konnte das System zu verwenden.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu

Im Folgenden werden Ihnen ein paar weitere Fragen speziell zu dem Wizard auf der Website gestellt.
Der Wizard ist der unten im Bild dargestellte Teil der Website.
Bitte wählen Sie jeweils eine passende Antwort aus.



Bitte stufen Sie auf der rechts liegenden Skala für jede Aussage ein, wie sehr Sie der Aussage zustimmen.

Die Fragen im Wizard waren leicht verständlich.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu
Die Anweisungen in der grünen Box waren leicht verständlich.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu
Das Ergebnis des Wizards war hilfreich.	stimme überhaupt nicht zu	○	○	○	○	○	stimme voll zu

Falls Sie Kommentare oder Vorschläge für weitere Funktionen auf der Website haben, würden wir uns freuen, wenn Sie uns diese hier mitteilen. (optional)

Welchem Geschlecht fühlen Sie sich zugehörig?

- ◯ männlich
- ◯ weiblich
- ◯ sonstiges
- ◯ keine Angabe

Wie alt sind Sie?

Alter (in Jahren): [ ]

Sind Sie an der Johann Wolfgang Goethe-Universität Frankfurt a. M. eingeschrieben oder an einer anderen Hochschule?

- ◯ Goethe-Universität
- ◯ andere Hochschule

In welchen Fachbereich sind Sie für Ihr Hauptstudienfach eingeschrieben?

[Bitte auswählen] ▼

In welchem Fachsemester befinden Sie sich momentan?

[Bitte auswählen] ▼

Welchen akademischen Abschluss streben Sie aktuell an?

- ◯ Bachelor
- ◯ Master
- ◯ Promotion
- ◯ Staatsexamen
- ◯ [ ]

Vielen Dank für Ihre Teilnahme!

Wir möchten uns ganz herzlich für Ihre Mithilfe bedanken.

Ihre Antworten wurden gespeichert, Sie können das Browser-Fenster nun schließen.