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Bachelors Thesis

How spatial split-attention effects in multimedia relate to cognitive load and visuospatial capabilities

Hur effekter av spatialt delad uppmärksamhet i multimedia relaterar till kognitiv belastning och visuospatiala förmågor

Alfred Norén & Daria Lindholm

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Supervisor: Roger Johansson
Examiner: Jean-Christophe Rohne

Abstract

The present study investigated firstly how spatial split-attention conditions in multimedia affects cognitive load, and secondly how individual differences in object-spatial imagery styles may affect this interplay. To test this, we included both objective measures (response time) and subjective measures (self-reports) of extraneous cognitive load in four different multimedia learning trials with spatially integrated versus separated multimedia presentations. The sample consisted mostly of university undergraduates. Results for time measurement indicated that spatially integrated formats were largely effective in reducing extraneous load ($p = <.001$, $\eta 2 = .43$). It was found in subjective measures that spatial visualizers experienced less extraneous load regardless of condition ($p = .042$, $\eta 2 = .05$) and through objective measures that object visualizers displayed more extraneous load in general ($p = .032$, $\eta 2 = .05$). The study did not find evidence for interaction effects of object-spatial imagery and spatial distance on cognitive load, which might have been a consequence of limitations on sample size ($n = 40$) and rough measurements, as there were tendencies in favor of such an effect.

Keywords: Cognitive load, multimedia learning, spatial contiguity principle, spatial split-attention, object-spatial imagery, visuospatial capabilities, OSIVQ, cognitive style

Sammanfattning

Denna studie hade som mål att i första hand undersöka hur spatialt delad uppmärksamhet (spatial split-attention) i multimedia påverkar kognitiv belastning, men även hur individuella skillnader i objekt-spatiala visualiseringstilar kan påverka detta samspel. För att testa detta inkluderade vi både objektiva mått (svarstid) och subjektiva mått (självrapporter) av ovidkommande kognitiv belastning (extraneous cognitive load) i fyra olika inlärningstester, med text och bild antingen spatialt integrerat eller separerat i material. Urvalet bestod mestadels av universitetsstudenter. Resultatet av tidsmätningen indikerade att spatialt integrerade format till stor del var mer effektiva för att minska belastning ($p = <.001$, $\eta 2 = .43$). Vi fann även genom subjektiva mått att spatiala-visualiserare upplevde mindre ovidkommande belastning oavsett tillstånd ($p = .042$, $\eta 2 = .05$) och genom objektiva mått att objekt-visualiserare tvärt om visade mer belastning i allmänhet ($p = .032$, $\eta 2 = .05$). Studien fann inte bevis för interaktionseffekter av objekt-spatiala visualiseringstilar och rumsligt avstånd på kognitiv belastning, vilket kan ha varit en konsekvens av begränsningar på urvalsstorlek ($n = 40$) och grova mätningar, eftersom det fanns tendenser till förmån för en sådan effekt.

Keywords: Cognitive load, multimedia learning, spatial contiguity principle, spatial split-attention, object-spatial imagery, visuospatial capabilities, OSIVQ, cognitive style

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How spatial split-attention effects in multimedia relate to cognitive load and visuospatial capabilities

Anyone who reads this thesis has probably at some point stared at an example in a book, manual or website and found themselves overwhelmed in a rather futile attempt to understand the content, perhaps even questioning if whoever created it was of the same species. How to present information in a way that makes it easy to grasp has been researched psychologically for decades and theories continue to evolve and help shape frameworks for instructional design choices (e.g. Mayer 2020; Miller, 1956; Sweller et al., 2011). Mayer’s cognitive theory of multimedia learning (CTML) attempts to create such a framework by developing design principles for material that incorporates words and illustrations (as in the combination of pictures and text, video and audio, etc.) with the goal to facilitate learning (Mayer, 2020). It is one of the main theories to expand on cognitive load theory (CLT) concepts and is showing rapid growth (Mutlu-Bayraktar et al., 2019; Mayer, 2020). The spatial contiguity principle is a strategy within the CTML framework which states that when text and illustrations are spatially close together rather than further apart in learning material, it is easier to process and leads to a better learning outcome (Mayer, 2020).

The concepts within these evolving theories are based on basic principles of cognitive psychology which govern the way we interact with our environment (Mayer, 2020, Sweller et al., 2011). They emphasize that if a message is to be communicated optimally, it is integral to consider constraints which regulate the way we process information. Fundamentally, we can only attend to a certain amount of information at a given point in time and our working memory capacity is limited in size (Baddeley, 2012). Cognitive psychology has for decades acknowledged that these core restrictions lay the foundation for our cognitive system and are common to all humans (Miller, 1956; D’Esposito & Postle, 2015). Beyond this baseline, there are ways in which we differentiate individually in our mental capabilities and in our preferences for processing different types of information (Riding, 1997). Such consistencies in cognitive dimensions which differentiate individuals, sometimes called cognitive styles, may be differently categorized based on models.

One such model is the three-dimensional object-spatial imagery and verbal style model which develops a distinction within the visual dimension from the more general visual-verbal model (Blazhenkova & Kozhevnikov, 2009). The newer model derives its structure from findings in neurocognitive theories and elucidates a distinction between visual appearances and spatial information, proclaiming that we vary individually in which of these information types we prefer to process. If so, we argue that CLT and CTML concepts which are based on visuospatial qualities of information, such as the spatial contiguity principle (Mayer, 2020), might need to consider these preferences. This is central to the current study, in which we will attempt to investigate the effects of divided attention (between spatially separated words and pictures) that the spatial contiguity principle is based upon. Further, we will explore how such effects may be affected by individual differences for preferences in mental imagery, based on the object-spatial dimensions described in the newer model for cognitive styles. We will also briefly look at how these individual differences may relate to gender and academic discipline.

Working memory

Fundamentally, we comprehend information by attending to small parts of information and form coherent wholes by grouping associative parts (Miller, 1956). A key component of the human cognitive system known as the working memory (WM) plays an essential role for this ability to form meaningful representations (D'Esposito & Postle, 2015). This concept of a WM that coordinates processing by briefly mentally maintaining some information when faced with multiple tasks - e.g. keeping a picture of a map in mind when taking verbal directions - has long been crucial to cognitive theories and several models have evolved to expand our knowledge regarding it (D'Esposito & Postle, 2015). A widely recognized conceptualization has been the multicomponent approach which has defined four basic elements of WM that interact to systematize processing when dealing with multiple sources of information (Baddeley, 2012). The model assumes three main "slave systems" governed by a "central executive unit." These slave systems are referred to as i) the phonological loop which holds auditory information, ii) the visuospatial sketchpad which holds visual and spatial information and iii) the episodic buffer which integrates separate information into unitary chunks. Also known as binding, this integration of different information has been theorized by the model to allow for stimulus representation and to affect how information is stored in our long-term memory. Long-term memory is a core cognitive concept, coined by Atkinson & Shiffrin (1968), of a practically infinite storage unit able to function through associative links. Learning may be viewed as successfully storing something to the long-term memory (Mayer, 2020). The interaction between long-term memory and WM is seemingly complex and may be viewed differently based on models. However, diverse theories agree that these two systems are critically linked (Baddeley, 2012; D'Esposito & Postle, 2015). The core of Baddely's model is the central executive with more general functions for attention and long-term memory storage. This executive has been theorized to enable shifting attention between stimuli, as well as dividing it between two relevant stimuli modalities such as words and pictures (Baddeley, 2012). Some prominent theories disregard the idea of switches between buffers, such as phonological and visuospatial, and instead view WM as a type of activation of long-term memory (Cowan, 2005; McElree, 2006; Oberauer 2009).

Traditionally, attention has been conceptualized as the resources which we focus on external information (consider the verbal directions in previous example), while WM has been viewed as an internal mechanism (consider the mental picture of a map in the previous example); in more current theories, the executive attention uses the same mechanism irrespective of internal or external information (D'Esposito & Postle, 2015). Currently prominent theoretical models have suggested that the allocation of attention to mental representations is the mechanism underlying how information enters WM (Cowan, 2005; McElree, 2006; Oberauer 2009). Known as state-based models, these contributions have suggested that attentional prioritization is the root of multiple known WM characteristics such as capacity limitation. A simplified explanation may be that since our attentional resources are restricted, so is our WM capacity. The limitations placed on WM resources set the affordances in relation to processing (D'Esposito & Postle, 2015). These cognitive principles are crucially involved in the comprehension of learning material and decisions for presentation have to consider them in order to successfully convey information in a way that makes it likely to be transferred to subjects' long-term memory (Sweller et al., 2011). This lays the foundation of cognitive load theory.

Cognitive load theory

The cognitive load theory (CLT) is based on the concept of how our brain processes information and how it stores it in our memory (Sweller et al., 2011). This theory was first introduced by Sweller in 1988. The basis of this theory is that when we process information we do it in our working memory, but limitations govern both how long we can hold on to the information and also how much of the information we can hold at the same time (Baddeley, 2012; D'Esposito & Postle, 2015). When we are faced with new information that we aren't familiar with we must use our working memory to process it. The harder the information is to interpret, the more pressure it puts on our brain since our cognitive functions are not limitless. This in turn creates what is called "cognitive load", and the more pressure we put on our brain when interpreting information, the more the cognitive load increases (Sweller et al., 2011).

Sweller et al. describes that according to CLT there are three different types of cognitive load - intrinsic, extraneous, and germane. The intrinsic load depends on the inherent nature of the material itself and its difficulty. The more familiar you are with the material that is presented - the less you need to use your working memory and can rely more on your long-term memory instead. The germane load is related to how the information transfers from our short-term memory to our long-term memory. It was expressed as "the effective load" by Asma and Dallel in their article about CLT (Asma & Dallel, 2020). They described that this type of load is created when we are processing new information and start to store it in our long-term memory, thus creating new knowledge which can be used in the future. Even if they did call this the effective load, they signify that it still follows the same rule as the other types - the loads are only beneficial until they start to be overwhelming for the individual. The last one is the extraneous load, which refers to irrelevant distractions that might occur while processing new information (Sweller et al., 2011). We chose to focus on this type of load in this study because it is the one that is most relevant to the spatial contiguity principle since it relates to how the learning material is constructed or presented to the individual (Sweller et al., 2011).

Extraneous load

As mentioned above, this type of load is created when an individual's attention is being distracted from the crucial part of the material. Some reasons as to why this might happen are described to usually relate to how the material is presented. There might for example be too many unnecessary words or pictures that draw attention from the crucial information in the material. This makes our brain process more information that is not beneficial to our learning. It creates a higher pressure on our working memory, which increases our extraneous load (Sweller et al., 2011). To achieve a lower extraneous load, i.e. use less of our already limited cognitive functions, Sweller et al. have underlined that we should compress the learning material and integrate it if it has several different parts, so that it is focused on the crucial information.

Information presentation and the split-attention effect

In the context of CLT, split-attention conditions have been described as when two or more distinct media components make up the essential parts for comprehension of some information – e.g., the combination of text and illustrations in explanation material – and the components are separated (Sweller et al., 2011). The split-attention effect is a concept for when such conditions lead to an increase in extraneous cognitive load, generally resulting in reduced learning efficiency (Kalyuga et al., 1999). Separation in this context includes temporal as well as spatial gaps which are thought to cause the subject to perceive multiple objects rather than one, in turn this requires the subject to spend cognitive resources on mentally integrating the pieces of information (Ayres & Sweller, 2014). The split-attention principle is thus to avoid such effects by integrating media components in informative material (Sweller et al., 2011).

A recent study investigated spatial split-attention effects and found no difference in learning when varying distance, though the authors mentioned that it might have been because of too small a spatial difference (de Koning et al., 2020). The study aimed to test efficiency of different interventions for split-attention conditions and found mental integration to be more efficient than having the subject physically integrate information by a drag and drop facility. Findings of this study have been compared to the imagination effect by Ayres (2020) which holds that information in working memory is more likely to be stored in long-term memory when a subject imagines a procedure or concept rather than just studying it (Leahy & Sweller, 2008). In this context, imagination should seemingly require subjects to spatially transform the material mentally.

Multimedia theory

A recognized theory which has expanded on CLT concepts is the cognitive theory of multimedia learning (CTML) which aims have been to provide guidelines for effective instructional design (Mayer, 2020). The foundation of this theory is that when you are presented with learning material you have a better chance to understand the information if it is presented in both words and pictures. Mayer's theory has found its roots in a few assumptions. Firstly, in what is referred to as the dual channel assumption, which states that we process the words we hear in one channel, the auditory one, and what we see in another channel, the visual (Mayer 2020). This assumption is related to Paivio's (1991) dual coding theory and Baddely's (2012) working memory model. Another assumption - the limited capacity assumption - is that our working memory has a limited capacity and a limited ability to process information (Mayer, 2020). When we are processing information actively, our mind creates mental images while starting to store the information in our long-term memory for future usage. This have been named as the active processing assumption (Mayer, 2020). These three assumptions together create the main foundation for CTML.

In the third edition of his book, Mayer (2020) have presented us with fifteen different multimedia principles that in different ways are supposed to make it easier for a person to learn the material. The principles have been founded upon the assumptions mentioned above and they are all about how to present information in the best possible way to enhance learning. Some of the principles can be combined while others are restricted to either static or dynamic settings, such as strategies relating to audio being unable to integrate with spatial effects (Mayer, 2020). One of Mayer's principles is the spatial contiguity principle, which is central to the aims of the present thesis.

Spatial contiguity principle

As previously mentioned, split-attention effects have been noted to occur in either temporal or spatial conditions. This distinction led to the creation of the spatial contiguity and temporal contiguity principles as two of the design principles in Mayer's theory for multimedia learning (Mayer, 2020). The spatial contiguity principle states that corresponding words and illustrations ought to be presented closer rather than further away from each other spatially to increase learning. An example of this, taken from the material of the current study, is demonstrated showcasing both the application of the principle in Figure 1 and the absence of it in Figure 2. The definition is distinct from split-attention effects but shares identical logic - that is, spending less cognitive resources on mental integration resulting in reduced extraneous load for integrated examples - which has been derived from the dual-channel assumption that we process visual and verbal information in different channels (Mayer, 2020; Sweller et al., 2011). Mayer have proposed three boundary conditions in which the principle is most applicable, they have been defined as when i) the subject is not familiar with the content, ii) the illustrations are rather unintelligible on their own and iii) the material is complex.

Figure 1 - Spatial contiguity principle applied

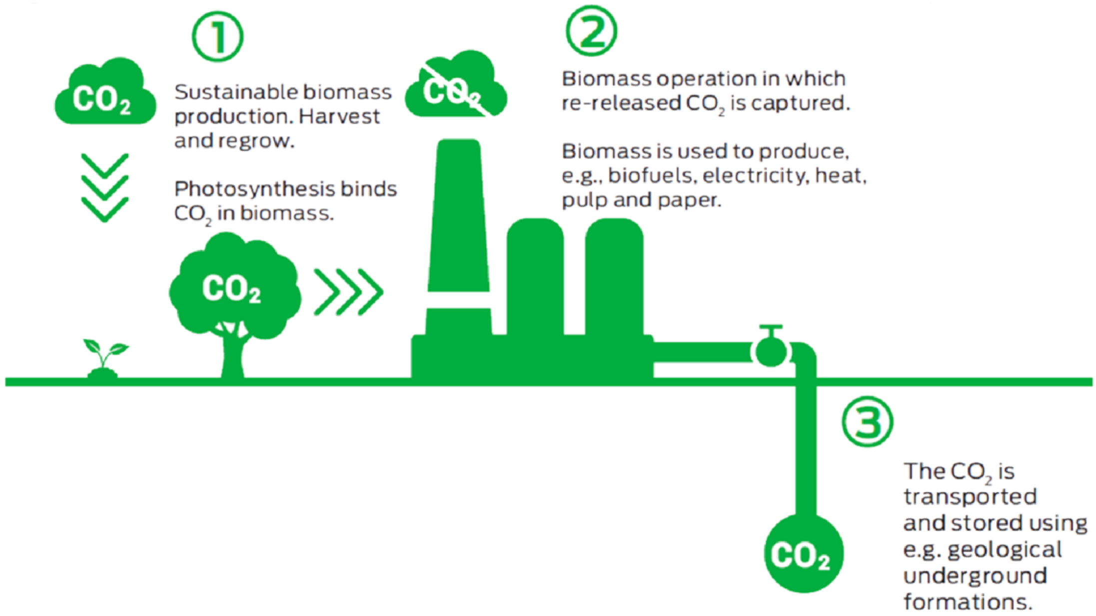
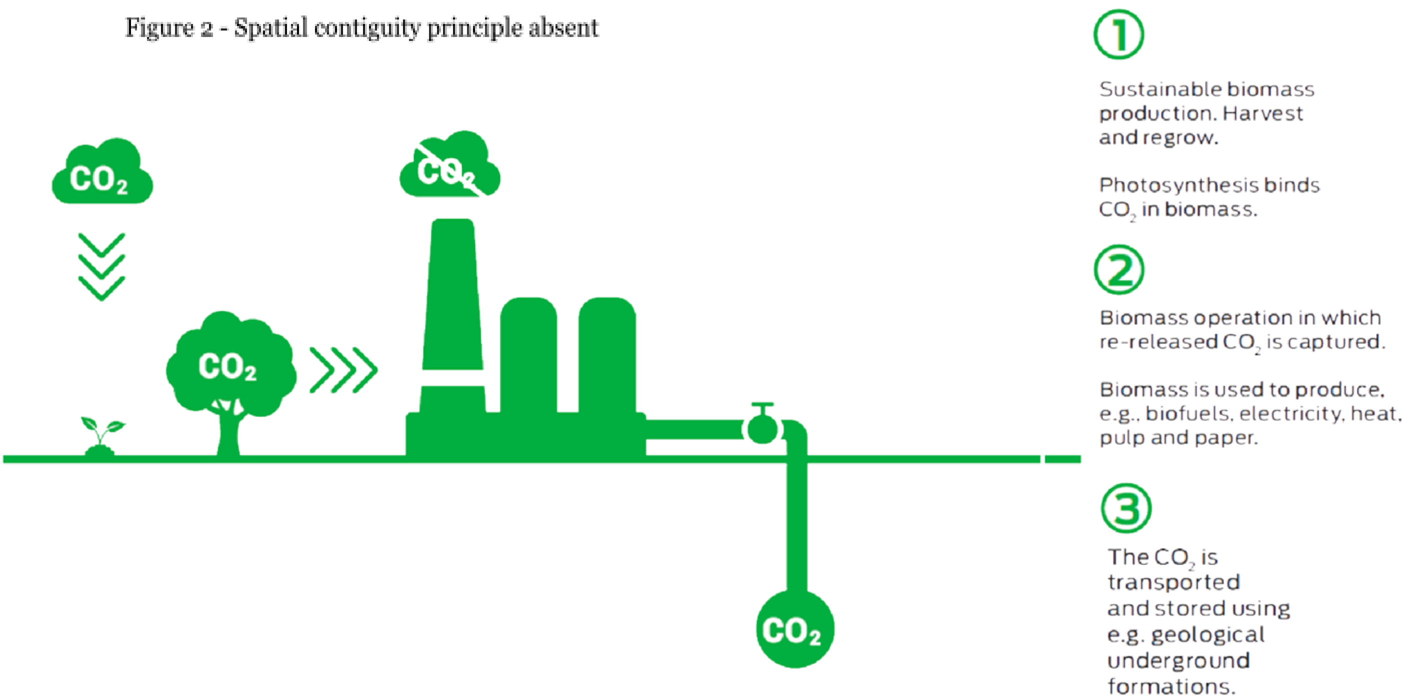


Figure 2 - Spatial contiguity principle absent



A recent meta-analysis on spatial contiguity and spatial split-attention effects in learning environments found a large and statistically significant effect for augmented learning associated with integrated designs, $g = .63$, $p < .001$ (Schroeder & Cenkci, 2018). The study questioned the boundary condition regarding complexity; it was seldom reported in literature and no statistically significant difference between varying complexity in examples was found. The analysis did not go into detail on how individual cognitive differences may act as moderators, which might have been a result of a lack of research on such effects. There was only brief mention of a study which investigated working memory capacity, multimedia comprehension skill and fluid intelligence as cognitive differences, which found main effects on learning but no interaction effects for conditions (Austin, 2009). Schroeder & Cenkci also quickly brought up spatial ability as a potential moderator in multimedia learning. The article they referenced to described an issue of lacking research on how different interventions and learning processes mediate effects of such individual characteristics (Renkl & Scheiter, 2017). Seemingly, there is good reason to suspect that relevant ways to capture such individual differences might be of interest for research in this area.

O-S-V cognitive style model

Cognitive style refers to some type of consistency in individual cognitive functioning (Riding, 1997). Models have varied in the dimensional qualities which relate to individual differences. A common model has been the visual-verbal model (e.g. Paivio, 1971; Richardson, 1977), which presumes individuals as tending to use either imagery or verbal-analytic strategies when performing cognitive tasks. This bipolar structure has been unable to relate to spatial and mathematical ability (Dean & Morris, 2003; Hegarty & Kozhevnikov, 1999) and has been challenged by a newer three-dimensional model which split the visual dimension into spatial and object styles (Blazhenkova & Kozhevnikov, 2009). Unlike the older version, the object-spatial-verbal model was based upon cognitive theories describing information processing and storage in the brain. The authors exhibited how neurological findings suggest that visual information is processed and encoded by two distinct subsystems that are localized in different parts of the brain. Visual appearance such as shape and color involve the ventral stream (through areas V1, V2, V4 to the temporal lobe) while spatial information such as object location and motion involves the dorsal stream (through areas V1, V2, V3, V5 to the inferior parietal lobe) (Cabeza & Nyberg, 2000; Gazzaniga, 2004). Confirmatory factor analysis has shown significantly better overall fit for data for the newer model in comparison to a bipolar one (Blazhenkova & Kozhevnikov, 2009).

A questionnaire named the OSIVQ (Object-Spatial Imagery and Verbal Questionnaire) assessing individual differences in object imagery, spatial imagery, and verbal cognitive styles has been developed. Principal factor analysis has shown clear distinct factor structure for the three dimensions and the questionnaire has demonstrated acceptable internal reliability as well as predictive validity across studies (Blazhenkova, 2008). Object imagery refers to analogous pictorial mental representations of objects and scenes. Spatial imagery on the other hand encompasses schematic representations of objects and patterns, as well as their transformations (Farah et al., 1988; Paivio, 1991). To illustrate, individuals high in spatial imagery – referred to as spatial visualizers – may more easily interpret a graph or diagram as depicting abstract relations, while individuals referred to as object visualizers have been shown to face adversity in deciphering such schematic representations, and to instead interpret them pictorially (e.g. Hegarty & Kozhevnikov, 1999; Kozhevnikov et al., 2002). Concerning information processing, object imagery is holistic and units have to be identified and separated in the visual field, while the obverse spatial imagery is regarded as sequential and is less reliant on identifying units (Kozhevnikov et al., 2005; Paivio, 1991). The verbal dimension may be summarized as relying on symbolic verbal representations. Both theoretical value and ecological validity has been supported by current research. (Blazhenkova & Kozhevnikov, 2009; Haciomeroglu & LaVenia, 2017; Höffler et al., 2017; Pérez-Fabello et al., 2018; Vannucci & Mazzoni, 2009). Some notable behavioral relations found include visual artists as object imagers while scientists and engineering students tend to be spatial imagers (Blazhenkova & Kozhevnikov, 2009); a small gender difference has also been observed by the creators of the model, with males tending to report higher spatial imagery whereas females report higher object imagery.

Aims and Research questions

Individual differences have been shown to influence cognitive load and act as filters in learning (Mayer, 2020). Variation in spatial abilities have frequently been mentioned in related literature and shown to impact learning outcomes (Heo & Toomey, 2020; Höffler, 2010), yet review articles have illustrated that there still exists a gap in research regarding its influence in different multimedia conditions such as spatial split-attention (Renkl & Scheiter, 2017; Schroeder & Cenkci, 2018). Further, it seems that there is as of yet little to no research relating the object-spatial-verbal cognitive style model to CTML concepts. The cumulative support for the three-dimensional model indicates that individual tendencies when processing information do not vary bipolarly between pictorial and verbal dimensions, but also in regard to spatial qualities such as transformations of spatial relations. Indeed, the same qualities that spatial split-attention effects concern. Subsequently, we argue that spatial visualizers, who generally use spatial transformations as a processing strategy, might need to spend less cognitive resources on mental integration.

In the context of the current theoretical framework, the aim of this study is to firstly investigate cognitive load in relation to the spatial contiguity principle and secondly to examine how individual differences in object-spatial imagery may influence this relation. Thus, we formulate the following research questions:

RQ1) How does spatial separation in multimedia material influence extraneous cognitive load?

RQ2) How does individual differences in object-spatial imagery capabilities affect the interplay of spatial separation in multimedia material and extraneous cognitive load?

In line with the theoretical background, we also define some specific expectations. Firstly, we expect that testing of RQ1 will show further proof of spatially integrated material being easier to process. Secondly, concerning RQ2 we define four additional hypotheses for the effects of visuospatial capabilities, i.e. object-spatial imagery. The central argument is that individuals with an aptitude for spatial capabilities may be naturally disposed to mentally integrate distinct information pieces when processing some material. By the same token, the holistically inclined object visualizers may prefer an undivided presentation and find it more demanding to integrate information in different locations. Thus, it is conceivable that a) cognitive load when processing multimedia material will be less for participants with spatial imagery aptitudes and more for those with object imagery aptitudes, since such material inherently involves mental integration of multiple information components (Mayer, 2020) and b) spatial separation will augment this effect.

In summary, the study aims to test the following hypotheses:

H1) Spatially separated material will cause more extraneous load for learners in general than spatially integrated material.

H2) Individuals with higher scores for the spatial imagery dimension will experience less extraneous load in multimedia material than those with lower scores.

H3) The effect in H2 will be more pronounced for separated rather than integrated conditions.

H4) Individuals with higher scores for the object imagery dimension will experience more extraneous load in multimedia material than those with lower scores.

H5) The effect in H4 will be more pronounced for separated rather than integrated conditions.

An additional goal of the study is to investigate behavioral relations and gender differences for the O-S-V styles to strengthen ecological validity of the model. Potential contributions are expected to assist further validation of recognized interactions between cognitive concepts and possibly generate new insight in how individual differences might influence such interactions. The current study partly aims to investigate how visuospatial capabilities may influence cognitive load in spatial split-attention conditioning, in turn possibly enabling new opportunities for research that contribute to theoretical frameworks and help facilitate better adaptation of informative material to specific groups of individuals.

Method

Participants

In this study the selection of participants was one of convenience. We reached out to our acquaintances and published a link to our experiment onto the social media platform “facebook”. This resulted in a total of 42 participants but unfortunately two of them had not properly responded to the questions since the timestamp in the trial was too short for them to actually have been able to process the information and decide on an answer. Therefore we had to delete these two participants' data from the study. This left us with a total of 40 participants. As we mentioned before, we had a subsidiary goal in this study, which was to test the ecological validity of the cognitive style model. Therefore we had several descriptive questions in the opening part of the experiment about the participants sex, age, highest achieved education, academic discipline and favourite hobby. Out of our 40 participants 18 were women, 21 men and one participant did not share their gender. In this study there were 35 individuals that were between the ages of 20-29, three of them were between 30-39, one was 59 and one individual did not share their age. The mean of the participants age was 25.4 whilst the standard deviation was 6.41. The majority of the participants were currently studying in university when they did the experiment. When it came to which preferred/prominent subject our participants had there was some variation. The most recurring subjects were psychology, math, language, natural science and engineering. When it came to the question of the participants' hobbies, most of them answered sports, gaming and arts.

Material

Multimedia material

The stimuli used in the study were mostly self-created in relation to boundary conditions of the spatial contiguity principle, which attempts to define circumstances for the relevant effect to be most likely (Mayer, 2020). This was done by finding appropriate informative multimedia material online and then modifying it in order to create two versions of it, one for each condition. This process carefully considered boundary conditions and took the following precautionary steps. Firstly, in relation to the first boundary condition, we only used material with information which was likely to be completely new to the participant, e.g. the operation of a relief valve in a specific motor. Secondly, the second boundary condition was considered by using material which was only fully discernible by inspecting both words and corresponding illustration. Finally, when constructing different versions for the different conditions, we aimed to create sufficient distance in separated versions without creating an unrealistic example. The third boundary condition for complexity was less considered in construction of material since it has been challenged by current research (Schroeder & Cenkci, 2018), enabling the study to examine the spatial contiguity principle in different materials, varying in intrinsic complexity.

Extraneous load questions

A self-report scale to measure perceived mental effort was developed by Bratfisch et al. (1972). It was later modified by Paas (1992) and became a popular tool for measuring cognitive load. These one-item scale measures were regarded as lacking from a psychometric perspective according to Klepsch et al (2017), and so a study was conducted to construct a more accurate way of measuring cognitive load which could independently measure different types of load. They also wanted to compare informed and naive ratings for cognitive load and if one was more accurate than the other. They used the Likert scale from Paas et al and then tested the questions through two studies to make sure they were both valid, reliable and also able to be compared to each other. They composed the questions in German and afterwards translated them into English. Klepsch et al found that measuring the cognitive load through a self-report scale without explaining the cognitive load theory to the participants was an appropriate way to measure cognitive load. They calculated the internal consistency for all of the different items of each scale, which was good. It was also demonstrated that both the informed and the not informed way of measuring cognitive load had good reliability, but the informed alternative takes more resources and time and is therefore not as suitable for bigger studies. The study also showed that the instrument they chose was not reliable for measuring germane load due to its inherent nature. But this did not have any effect on the reliability of the other types of loads. To test the validity of the experiment Klepsch et al. studied if the participants' ratings showed the theoretical assumption for every task they conducted during the experiment. The study showed a general reliability, the mean of the Cronbach's alpha was .86 for the extraneous load scale. The validity in this study was proved to be at a successful level. To confirm this, they compared the different ratings of the participants with the theoretically proved outcomes. This was possible since all of the tasks were constructed to either be high or low in ICL; ECL or GCL. The ratings for all three of the loads turned out to be very different when it came to low versus high groups of tasks for each load and for the extraneous load it came to be: $t(89) = 7.28$, $p > .001$, $d = .94$ (Klepsch et al., 2017).

For our study, since we were only interested in cognitive load caused by changes in presentation format, we included the three questions that measured extraneous load independently and used the 7-point Likert scale that ranged between strongly agree and strongly disagree. Below are the questions we used that were composed by Klepsch et al.

During this task, it was exhausting to find the important information.

The design of this task was very inconvenient for learning.

During this task, it was difficult to recognize and link the crucial information.

OSVIQ

We used the object-spatial imagery and verbal questionnaire (OSIVQ) to gather data on individual differences that divided our participants into the different cognitive style dimensions. No modifications to the questions were made. This questionnaire contains 45 questions and was created by Maria Kozhevnikov and Olesya Blazhenkova (2009) to determine if you were more verbally, spatially or objectively inclined. The questionnaire is a tool that is used when there is a need to understand cognitive differences in learning between individuals. After a person has answered all questions their scores are calculated for each cognitive style. The test was constructed by Blazhenkova and Kozhevnikov after they had completed three studies in total on how to differentiate cognitive styles. They built and validated a new self-report instrument for OSV styles that did not exist earlier. To do this the three studies also showed an admissible reliability and ecological validity. They used different tests that were proven to show ability of object, spatial and visual abilities (e.g. rotation tests for spatial ability) and then compared those to the questionnaire. The first study they conducted showed an acceptable internal reliability for all of the three scales for the OSIVQ. They also conducted a principal component analysis on the items in the OSIVQ which showed that the items made to determine the object, spatial and verbal ability was supported. To measure the reliability of the questionnaire they performed a test-retest. This showed $r = .73$, $p < .001$ for the verbal scale, $r = .75$, $p < .001$ for the object scale and $r = .84$, $p < .001$ for the spatial scale. These findings were above the minimum level of McKelvie (1994) test-retest coefficients except for the verbal correlation which was just a little below. In the third study they did find that the questionnaire had good ecological validity. The study also found that men reported higher on the spatial questions than women and that women reported higher for object questions than men. But the study did not find any significant differences in genders as a whole (Blazhenkova & Kozhevnikov, 2009).

Psychopy & Time measure

Psychopy is an open-source program that allows you to create different forms of simple-to-complex materials on your computer. It is available to download for free and uses Python to run the material (*Peirce, J. W. (2007). PsychoPy—psychophysics software in Python. Journal of neuroscience methods*). We created our experiment here and made four versions of it where the conditions were in different order. This program is also capable of registering exact time measurements for each section distinctly, which was used as our objective measurement of cognitive load in learning trials. This choice was partly based on a study that compared how different measures for cognitive load were better fit for different types of load and found that response time was most sensitive to manipulations of extraneous load processing (DeeLeuw & Mayer, 2008).

Pavlovia is a web page that makes it possible to upload an experiment and be able to share it online with other people (*Pavlovia*, n.d.). This allowed the study to be run entirely online. We uploaded our experiment here and had it accessible for 18 days until we had enough participants. A Google script was used to randomly redirect participants to one of four different versions of the experiment. When we had 40 participants that had completed the experiment, 10 for each version, we decided to close the experiment.

Design & procedure

When participants opened up the experiment, they were asked descriptive questions (e.g. gender and academic discipline). In the beginning of the experiment, there was an introduction where it was stated that the study was voluntary, anonymous and that they could withdraw their participation at any time. Then, after another introductory screen, the OSIVQ questions followed one by one. Afterwards participants received a final introduction before being exposed to four multimedia learning trials one at a time. Each trial was composed of three sections before being looped with a new stimulus. Firstly, participants were faced with a multimedia learning stimulus, presented in either the spatially integrated condition or the spatially separated condition (e.g. Figure 1 and Figure 2). There was not a time limit, but participants were asked in the introduction to hit a key to continue as soon as they had a decent understanding of the content, in order to facilitate time measurement validity. After engaging with the material and continuing, they were immediately asked the three questions (one by one) designed to measure the extraneous load they experienced when processing the material. Then, an objective statement regarding the content of the material that was rated as true or false by the participant. This was used as a rough learning outcome measure but was mainly created in order to give incentive for participants to engage with the information in the material. Once these steps were completed, the loop function initiated another trial with different multimedia material. As mentioned, each participant completed four trials each in total. Finally, an end card thanked the participants and they were provided with an email address to one of the researchers if they had questions or wanted their information removed from the study.

Order of the multimedia stimuli was randomized through the psychopy loop function. As aforementioned, every participant had been randomly assigned to one of four possible versions. The four versions were created in order to randomize which of the four materials were presented in separated conditions and which were in integrated conditions; the experiment versions were identical in all other aspects. As each experiment always had two spatially integrated trials and two spatially separated trials, the four versions constituted all possible arrays of stimuli versions. In conjunction with the randomized order, there was complete counterbalancing of all possible effects. The study used a complete repeated measures design by presenting multimedia material in both conditions - i.e., spatially separated and spatially integrated - twice for each participant.

Analysis

Preliminary to analysis in relation to hypotheses, a mean value for learning outcome measures - ranging from 0 to 1 - was assessed in order to validate participant engagement. For every participant we calculated a mean for extraneous load out of the two tasks given in separated conditions and another mean for integrated conditions. This was done for both subjective ratings and response time measurements. A median split was used to define high and low groups in cognitive style dimensions based on scores derived from the OSIVQ. A follow up between-subject analysis of general differences between the four stimuli-materials was also done by calculating means and SD for extraneous load responses and response times for the different stimuli across participants.

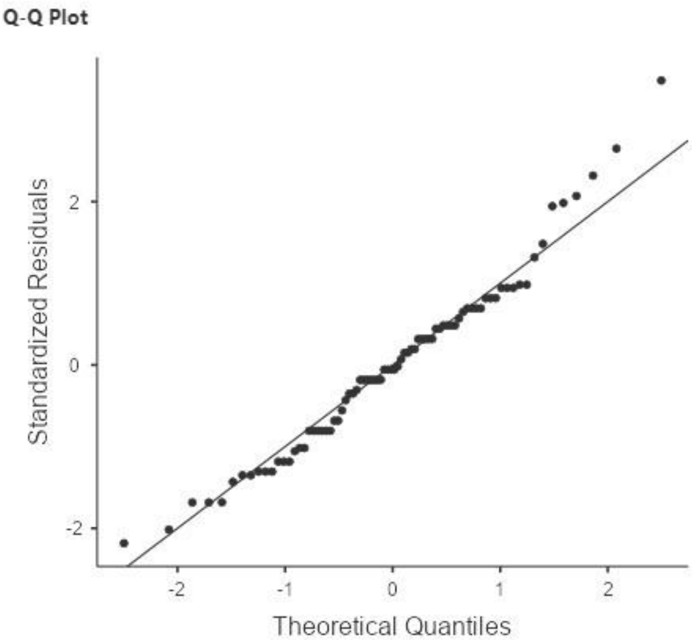
To investigate the first research question and test the first hypothesis (H1), we conducted repeated measures analyses of variances (RM-ANOVAs), one for mean scores on subjective extraneous load ratings and one for mean scores for response time. The second research question was explored in tests for hypotheses 2 through 5 (H2, H3, H4, H5) which was done by conducting the same analyses as for H1 but now including high and low groups for scores on spatial imagery and object imagery as between subject factors in RM-ANOVAs. In addition, the verbal dimension was also tested through the same analysis.

Descriptive analysis was done by looking at OSIVQ scores in relation to gender and proficient discipline which was categorized as either STEM subjects or social sciences.

Results

Preliminary findings: The mean value for learning outcome, ranging from 0 to 1, turned out to be slightly above .8, representing an 80% correctness for answers. After conducting RM-ANOVAs for relevant variables, nothing was found to significantly influence learning outcome. Between-subject analysis exhibited similar standard deviation for subjective as well as objective cognitive load measurements across the four stimuli-materials. Q-Q plots showed acceptable normality for the data (Figure 3).

Figure 3



Main findings: Computed RM-ANOVAs indicated significant differences between separated and integrated examples for time measurements, $F(1, 39) = 95.2$, $p = <.001$, $\eta 2 = .43$, with longer times for spatially separated conditions (Figure 4); subjective extraneous cognitive load measurements did not differ significantly between presentation formats, $F(1, 38) = 2.46$, $p = .125$, $\eta 2 = .03$ (Figure 5).

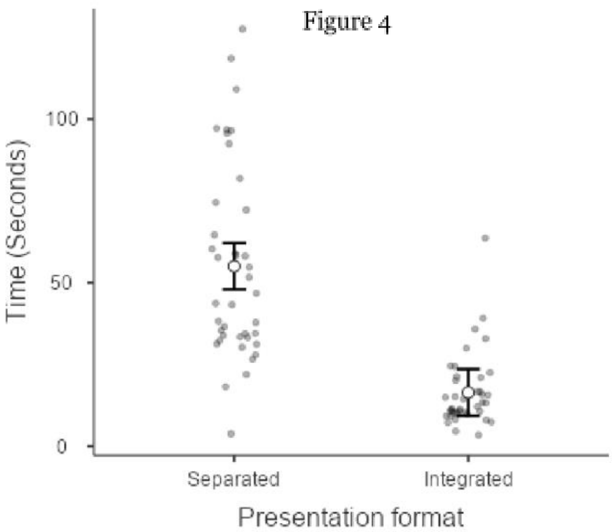


Figure 4

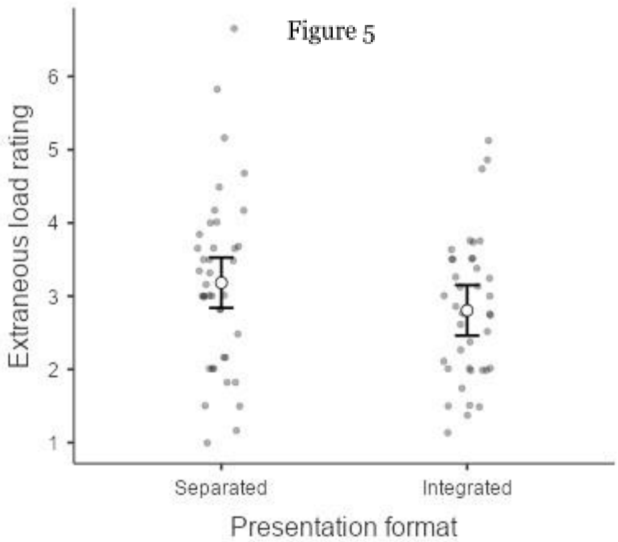


Figure 5

Further conductions of RM-ANOVAs found that participants with relatively high scores for the spatial dimension rated their extraneous load significantly lower than participants with relatively low scores across learning examples independent of condition, F(1, 38) =

4.41, p = .042, η2 = .05 (Figure 6). A similar general effect was not found statistically significant for time measures, F(1, 38) = .079, p = .781, η2 = .001 (Figure 7).

Figure 6

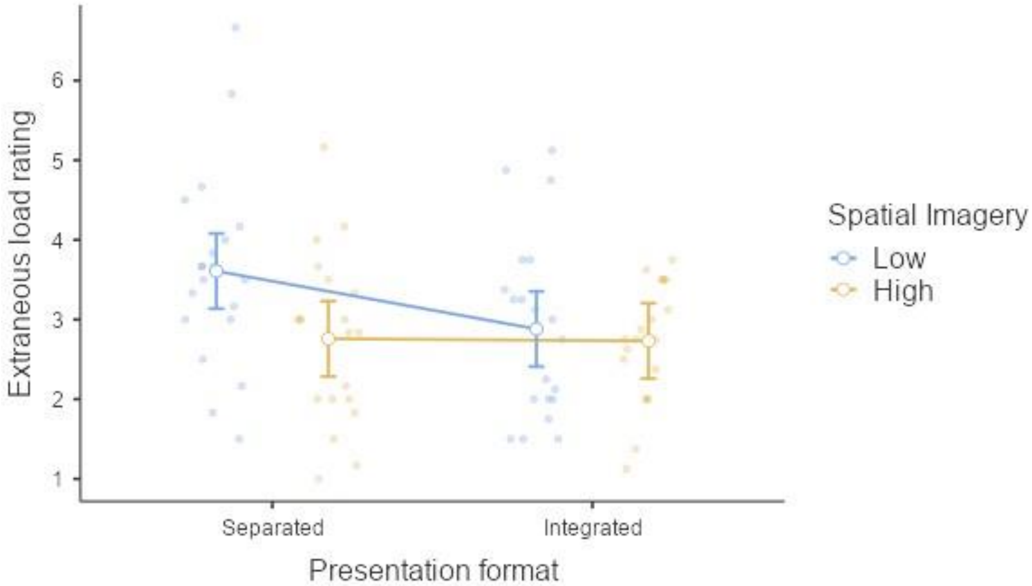
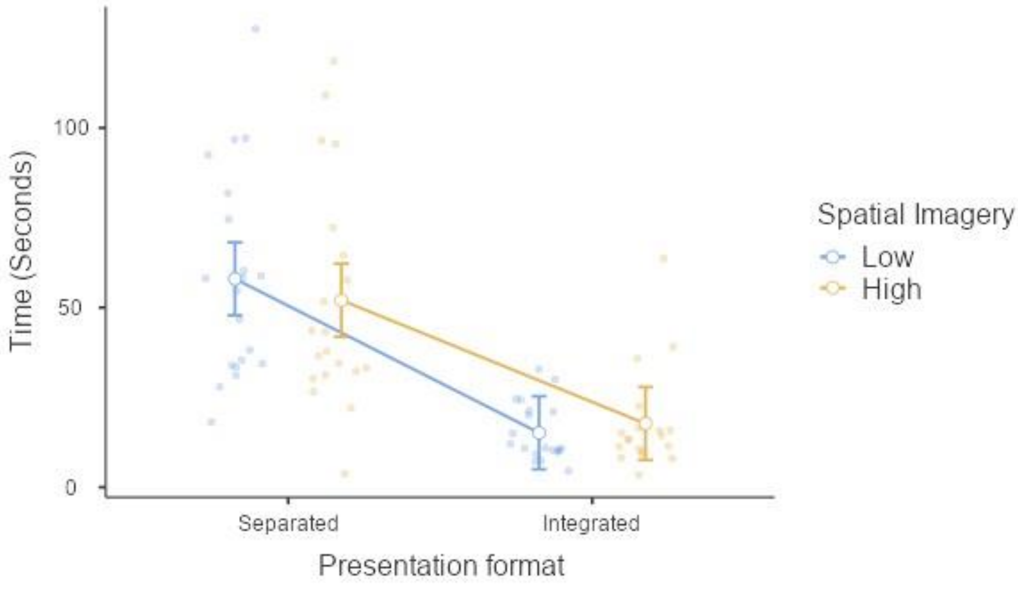


Figure 7



Statistical significance was not found for an interaction between spatial imagery scores and presentation condition to affect extraneous load in either subjective measures, F(1,38) = 2.19, p = .147, η2 = .03, or objective measures, F(1, 38) = 1.16, p = .288, η2 =.005. It was found in calculated RM-ANOVAs that participants with relatively high scores for object dimension spent significantly more time on learning examples overall, F(1, 38) = 4.96, p = .032, η2 = .05 (Figure 8). A comparable general effect was not found to be significant when analyzing subjective ratings of extraneous load, F(1, 38) = .283, p =

.598, η2 = .004 (Figure 9).

Figure 8

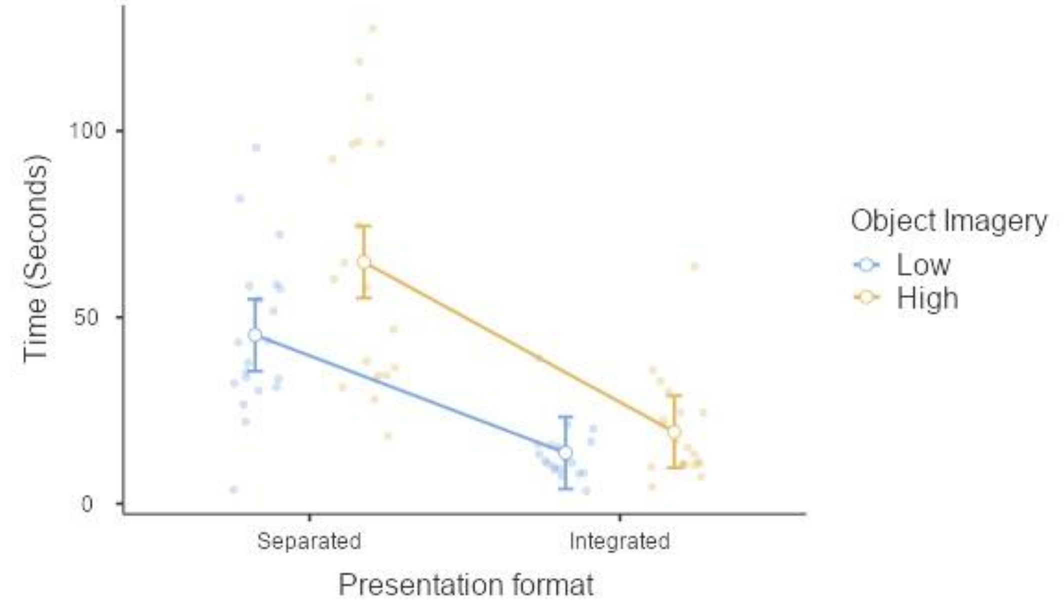
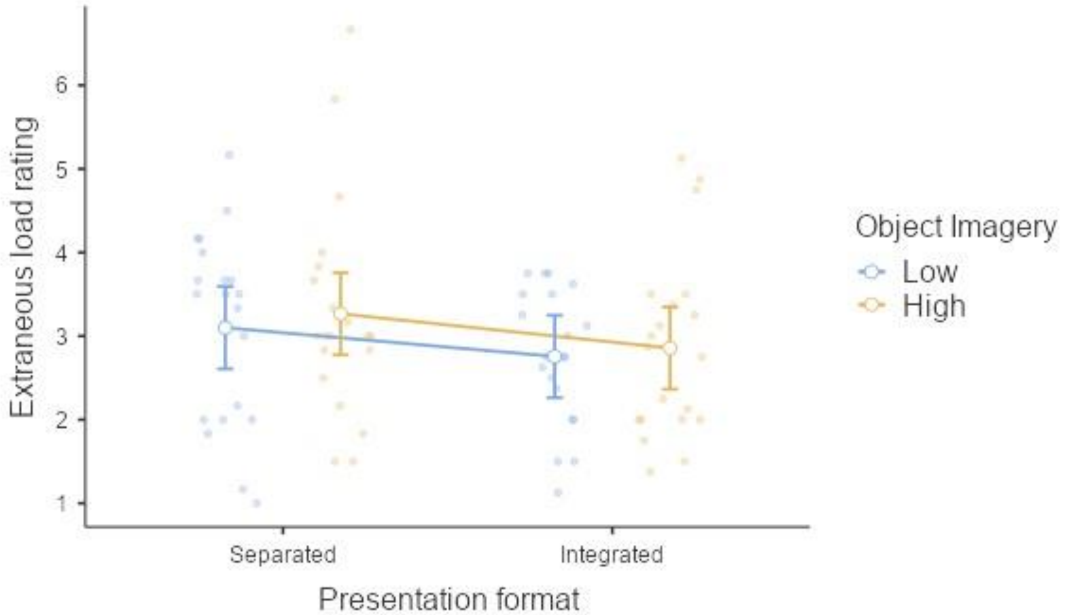


Figure 9



An interaction effect for higher scores in object imagery leading to increased extraneous load in separated conditions compared to integrated conditions was found to be marginally significant for time measurements, $F(1,38) = 3.30$, $p = .077$, $\eta 2 = .014$. Subjective measures did not find significant interaction effects relating to object imagery $F(1,38) = .02$, $p = .89$, $\eta 2 = 0$. Finally, RM-ANOVAs exhibited no effects in relation to the verbal dimension.

Descriptive findings: There was a small gender difference indicative of males as slightly more spatially oriented (n = 21, mean = 3.25) than females (n = 18, mean = 2.85).

STEM students (n=13) were relatively high in spatial scores while most students in social science disciplines (n=17) had lower scores in spatial dimension (social sciences mean = 2.84, STEM mean = 3.5), social science students scored slightly higher in object (social sciences mean = 3.69, STEM mean = 3.24) and verbal dimensions (SS mean = 3.31, STEM mean 2.82).

Discussion

The present study investigated in the first research question the effect of spatial separation in multimedia material on cognitive load. Then, it was explored in a second research question how individual cognitive differences in visuospatial capabilities may affect this interplay. These individual differences were derived from scores on the object-spatial imagery and verbal questionnaire (OSIVQ). Additionally, the study also examined ecological validity for the O-S-V cognitive style model in relation to participant gender and academic discipline.

Our analysis consisted of both subjective and objective measures of extraneous cognitive load, as well as a smaller test for learning outcome. General learning outcome was about 80% in correctness, signifying proper engagement with material. It was not shown to be differently influenced by individual factors, reflecting that disparities between groups in subjective ratings and time measurements suggest a need to spend more or less cognitive resources in order to acquire the same outcome. Main findings gave insight into the research questions. Firstly, research participants spent longer time processing information in spatially separated conditions. Secondly, it was found that individuals with higher scores for spatial imagery – i.e. spatial visualizers - rated their extraneous load as less than others did after processing multimedia material; a small tendency that spatially separated conditions in material augmented this effect could be observed in plots (mainly in subjective measures, see Figure 6) but an interaction effect was not found to be statistically significant. Finally, participants who obtained higher scores for the holistic object imagery dimension – i.e. object visualizers - spent more time processing multimedia material. This effect tended to be more pronounced in separated conditions when looking at time measurements (see Figure 8), but such an interaction effect was only marginally significant.

Results of the study generally aligned with our expectations with some exceptions. The first hypothesis (H1) was confirmed in time measurements which indicated a large main effect that spatially separated formats of multimedia material seemed to cause more extraneous load on a general level. Exhibited main effects of visuospatial capabilities followed the hypothesized directions that, as found through subjective measures, spatial visualizers experienced less extraneous load in general when they processed multimedia material (H2), and as found through time measures, that object visualizers displayed more extraneous load when they processed such material (H4). Somewhat unexpectedly, only one type of measure was able to provide statistical significance for each of the three main effects. We also anticipated significant results for hypothesized interaction effects, but this was not the case. However, this might have been a consequence of limitations for the study as there were notable tendencies in results which aligned with our expectations. Specifically, as stated in the third hypothesis (H3) extraneous load tended to increase less in separated conditions for spatial visualizers, and corresponding to the fifth hypothesis (H5), an opposite tendency for object visualizers experiencing amplified load in separated conditions was marginally significant. Thus, the study did not manage to provide evidence for these interaction effects, but neither was there anything in our results to contradict their existence.

Descriptive findings implied that spatial visualizers are more associated with STEM subjects which is in agreement with earlier research and supply further evidence of the relation (Blazhenkova, 2009). The small gender difference that men tended to be spatial visualizers is also in line with earlier findings (Blazhenkova & Kozhevnikov, 2009).

The finding for the first research question which indicated that participants' cognitive load was greater when words and illustrations were spatially separated were to be expected considering the substantial theoretical background for the spatial contiguity principle and spatial split-attention effects (Mayer, 2020, Schroeder & Cenkci, 2018; Sweller et al., 2011). The result can be interpreted in relation to concepts within the theoretical network as a need to spend cognitive resources on mental integration in spatially distant conditions. However, it is worth mentioning that some recent studies have not managed to replicate such effects (Florax & Ploetzner, 2010; de Koning et al., 2020; Schmidt-Weigand et al., 2010). This study provides additional current proof in favor of this type of effect and the design principle.

The main effects for visuospatial capabilities align with each other and suggest that multimedia formats are especially helpful for individuals with cognitive inclinations for sequential spatial imagery, and less so for those who tend to rely on holistic object imagery. Interestingly, these findings may be related to the individual differences principle presented by Mayer in the first edition of Multimedia Learning (Mayer, 2001), which partly states that good multimedia design is particularly effective for high rather than low spatial learners. This notion was scrapped in later publications (Mayer, 2009; Mayer, 2020) while only the other part of the principle regarding learner experience was recast as a boundary condition. The reasoning behind this decision is not explained in the other editions. The theoretical rationale behind the notion is described by Mayer (2001) in the following manner:

> High-spatial learners possess the cognitive capacity to mentally integrate visual and verbal representations from effective multimedia presentations; in contrast, low-spatial learners must devote so much cognitive capacity to holding the presented images in memory that they are less likely to have sufficient capacity left over to mentally integrate visual and verbal representations. (p.161)

This argumentation aligns with our results, and they serve as further indication of such effects. These findings also support previous research which has shown high spatial ability to positively influence learning outcome in multimedia learning (Heo & Toomey, 2020; Höffler, 2010). Although spatial ability and spatial visualization style are distinct concepts, their measures overlap and the concepts are strictly related (Blazhenkova & Kozhevnikov, 2009). Similarly, although previous studies have generally investigated learning outcome, CLT and CTML regards reduction in extraneous load to be directly linked to learning outcome (Mayer, 2020, Sweller 2011).

Proposed interaction effects for visuospatial capabilities and the spatial contiguity effect remain a theoretical possibility. The observed tendencies may be related to the same logic and theoretical structure as described for the main effects. According to theories for spatial split-attention effects, spatial distance in multimedia material increases the cognitive burden of mental integration (Sweller et al., 2011, Mayer, 2001). If so, the advantage in mental integration proposed for spatial visualizers should serve to negate some of this burden. The recent study which found mental integration to be a superior intervention to a manual physical integration intervention for spatial split-attention conditions (de Koning et al., 2020) may be considered as relevant in this context. The comparison of this result to the imagination effect made by Ayres suggests that the mental imagery related to the spatial transformations is advantageous for learning in spatial split-attention conditions. Considering that such imagery is natural for spatial visualizers (Blazhenkova & Kozhevnikov, 2009), it should follow that it would require less cognitive resources. The obverse object visualizers should then find such a strategy less preferable, probably causing more cognitive load. The study could however not supply proof for this.

A permeable theme for the findings of this study is that there is a need to spend cognitive resources when mentally integrating distinct pieces of information into a whole, and that the intensity of this need may vary between individuals based on visuospatial capabilities. This type of interplay between specific individual differences and how we process visual information gains importance as digital environments expand and user interfaces are used in conjunction with more of the essential functions in society. In order to steer progress for information accessibility, usability and learning in an unbiased sense, we argue that it is essential to thoroughly analyze the way that some individuals may encounter disadvantages in the processing of common presentation formats. From this perspective, the choices that digital designers make can not only help to generate efficiency, but also to some extent equality in society. Speculative implications in relation to the study in this general context is that individuals who are more holistically inclined in their cognitive functioning might find it more troublesome to process less unitary forms for presentation of information, rendering such design choices and multimedia more effective for individuals with high spatial capabilities. By further investigating this relation, as well as the ecological validity for models of cognitive functioning, applications may find relevance in design of both learning and usability. However, the aforementioned implications are only hypothetical, and much more research is needed in relation to observed effects for visuospatial capabilities. The study did manage to generate valuable insight for both research questions, however any assertive inferences are evidently restricted.

Limitations that were placed on this study should be considered when viewing the results. The study was mainly constrained in relation to the sample. The sample size was relatively small ($n = 40$) which increased the margin of error and made it more likely that potential effects went undetected. The choice to use a complete repeated measures design may have helped counterbalance this issue. However, the small size also limited our analysis to a median split for cognitive styles, making the already quite rough measures more so. We were also restricted to convenience sampling which increased the likelihood of sampling errors, further reduced power and led to lower generalizability. The choice to use time measures discouraged us from having a fixed time for trials. In everyday life we are often restricted in time, and it is possible that a fixed time setting would have led to different results. Since participation was entirely online and without supervision, it is also possible that participants had errors we were unaware of. We did however look at response times and learning outcomes and found no reason to doubt proper engagement. The different conditions for stimuli used in trials were self-created, generating some uncertainty for material. Although no notable differences were found for results between the various materials in the analysis, it does not fully validate the material.

Future research is needed to investigate the relationship between visuospatial capabilities and spatial split-attention effects in multimedia. The current study found promising results and provides some potentially fruitful venues for research. We recommend future studies to explore the effect of object-spatial imagery on multimedia concepts and instead create participant groups through a preliminary screening for high versus low scores for imagery dimensions. Studies should also explore a fixed time-limit for learning and different objective measures for cognitive load, such as eye-tracking and as transfer tasks which a study found to be more related to extraneous load in spatial contiguity conditions than EEG (Makransky et al., 2019). As our results supported the theoretical basis of the mysteriously abandoned part of the individual differences principle once brought forth by Mayer which states that multimedia design is especially efficient for individuals with high spatial capabilities, we encourage future studies to further explore this effect.

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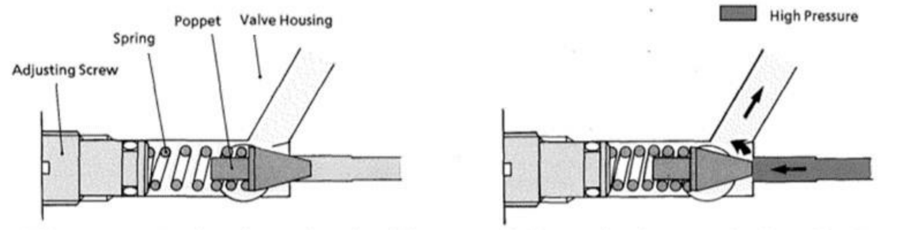
Appendix

■ **Operation of Relief Valve**



This power steering is equipped with a direct-acting relief valve to restrict the maximum pressure in the hydraulic circuit and to prevent breakage of the hydraulic equipment.

When the pressure in the hydraulic circuit exceeds the relief valve setting pressure in such a case that the maximum steering angle of the front wheels is reached or road resistance to the front tires is too great, the spring (2) is compressed to generate a gap between the poppet (3) and the valve housing (4). The pressure-fed oil flows to tank port through the gap so that pressure rise is restricted.

The relief valve setting pressure can be adjusted by turning the adjusting screw (1).

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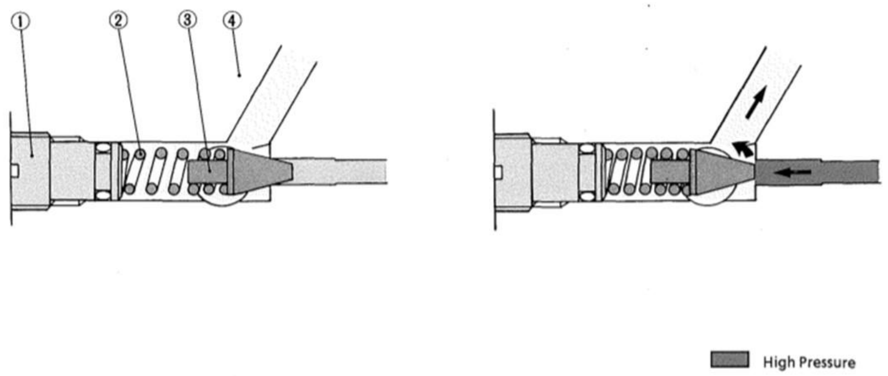
■ **Operation of Relief Valve**



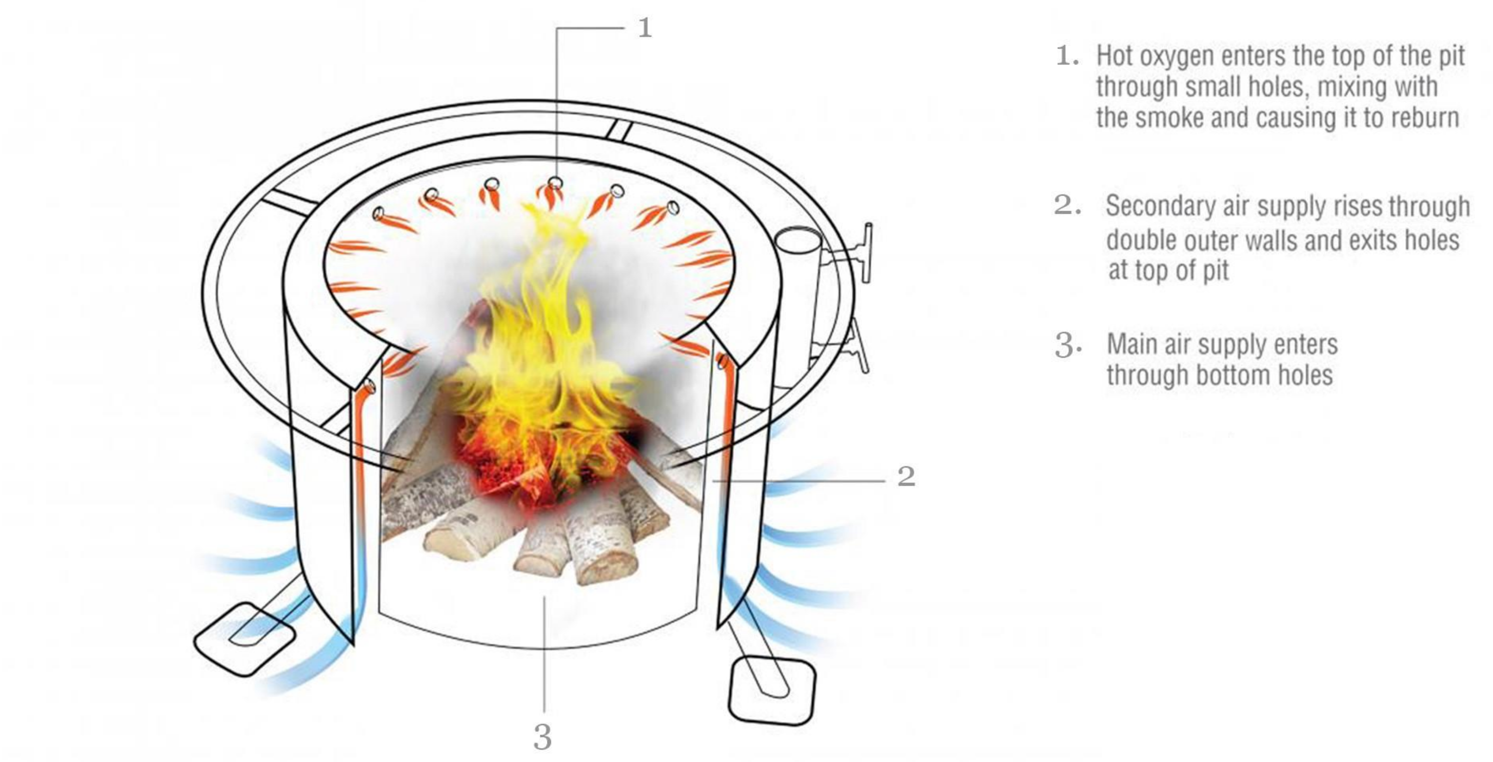
B177F706

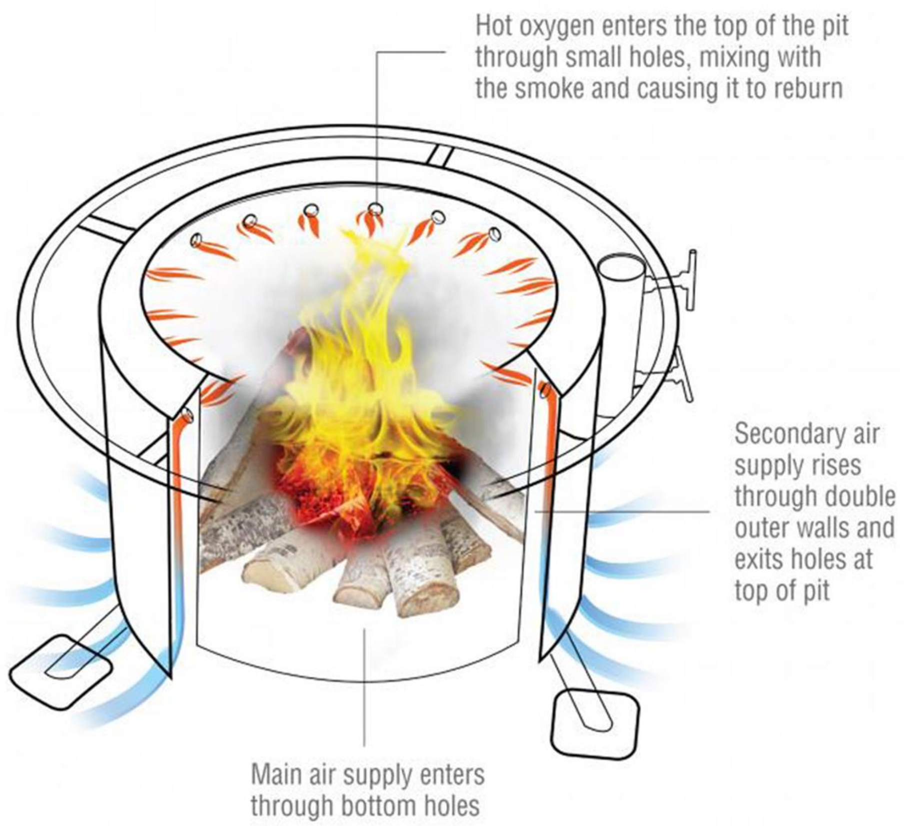
(1) Adjusting Screw (2) Spring (3) Poppet (4) Valve Housing

This power steering is equipped with a direct-acting relief valve to restrict the maximum pressure in the hydraulic circuit and to prevent breakage of the hydraulic equipment.

When the pressure in the hydraulic circuit exceeds the relief valve setting pressure in such a case that the maximum steering angle of the front wheels is reached or road resistance to the front tires is too great, the spring (2) is compressed to generate a gap between the poppet (3) and the valve housing (4). The pressure-fed oil flows to tank port through the gap so that pressure rise is restricted.

The relief valve setting pressure can be adjusted by turning the adjusting screw (1).


1
2
3
1. Hot oxygen enters the top of the pit through small holes, mixing with the smoke and causing it to reburn
2. Secondary air supply rises through double outer walls and exits holes at top of pit
3. Main air supply enters through bottom holes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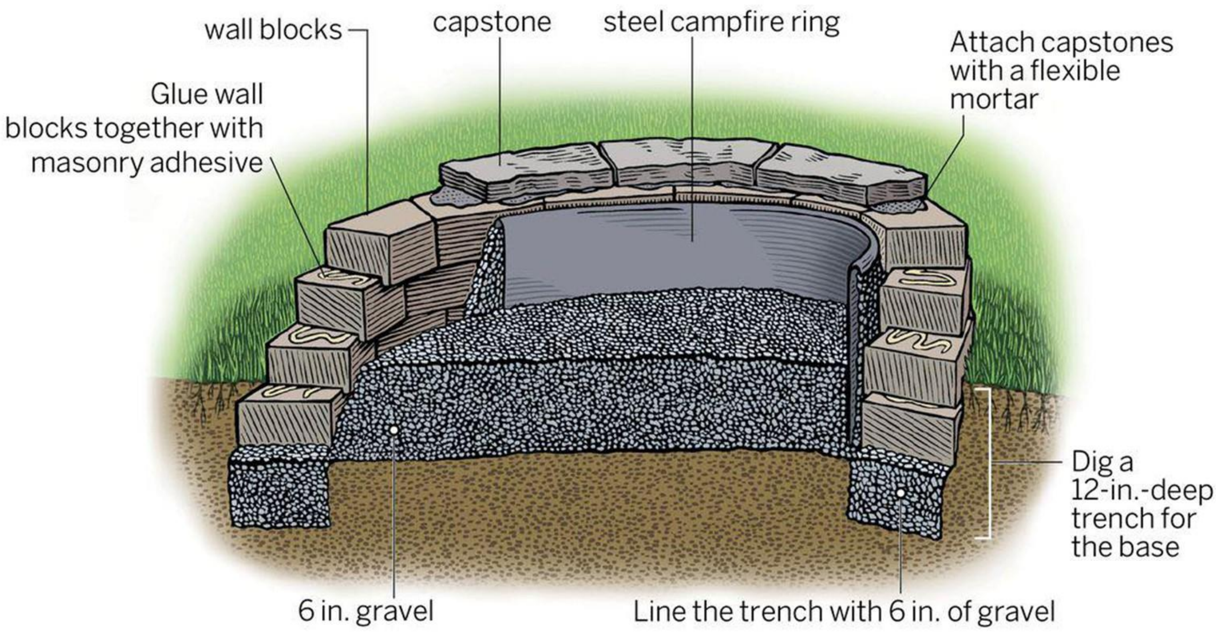

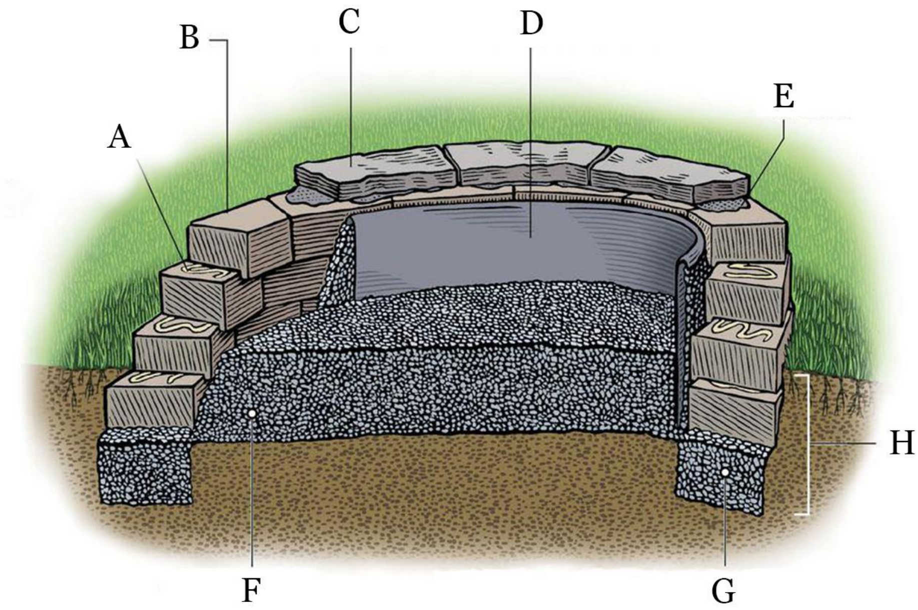

(A) Glue wall blocks together with masonry adhesive

(B) wall blocks

(C) capstone

(D) steel campfire ring

(E) Attach capstones with a flexible mortar

(F) 6 in. gravel

(G) Line the trench with 6 in. of gravel

(H) Dig a 12-in.-deep trench for the base