Why and How Diagrams Help in Teaching Syllogistic Skills: An Embodied Account

Menno van Calcar

Abstract: Teaching syllogistic reasoning is often perceived as teaching pupils the purely formal rules of deductive inference. According to this common conception, such reasoning is a highly abstract skill, one that is carried out by the processing of syntactically encoded representations of the premises. This paper argues that syllogistic reasoning may, indeed, keep clear of the concrete contents of the premises, but is realized by a skill that is less abstract than rule-following. It argues that reasoning is continuous with our other skills and is realized by our capacities to deal with spatial situations. This explains why the use of Venn diagrams, a much-used technique for evaluating syllogistic inferences, is effective: the spatial layout expressed by the diagrams directly activates the actual mechanism reasoners use. Teachers are therefore right when they teach the use of such diagrams. This paper also argues that using tools that tap into our capacities to deal with a *three*-dimensional world will be even more effective and corroborates this argument with an experiment in which three-dimensional Venn diagrams were used to train high school pupils.
Keywords: syllogisms, spatial capacities, three-dimensional Venn diagrams, embodied cognition

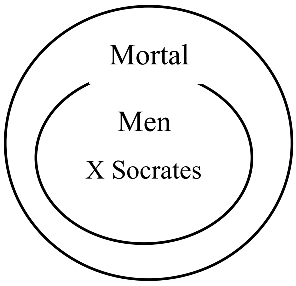
Introduction

It is not contested that teaching should foster critical thinking skills, on any level of education. One of the most important ones of these is the skill to reason. In a world rife with complex situations, and bad and deceptive reasoning, the skill to distinguish between valid and invalid inferences is essential for problem solving and decision making. Since Frege, many powerful formal logical systems have been developed. But most of us, and most of our pupils, don't encounter, or use, reasoning in formal guise. In real life, we mostly encounter reasoning in written or spoken assertions, and the relations that are supposed to hold between those assertions (Johnson, 1996). In addition, formal logical systems are often quite inaccessible, unattractive to the not-mathematically-inclined, and counter-intuitive (Larvor, 2004). Informal logic, on the other hand, is about statements and inferences in natural language. This makes it recognizably relevant as something that plays a role in all domains of human life, makes it accessible to most pupils, and makes it suitable for many different didactical approaches. That's why informal logic should be the basis of teaching reasoning skills.[1]

[1] Many even equate informal logic with critical thinking itself, e.g., Siegel, 2007.

Syllogistic reasoning (e.g. all men are mortal, Socrates is a man, therefore Socrates is mortal) is at the core of informal logic, works with everyday sentences, and its basics can be easily grasped. In other words: teaching syllogistic reasoning is very suitable for fostering critical thinking skills. Working with syllogisms specifically trains the ability to tell valid (does the conclusion really follow?) from invalid arguments, enhancing the ability to be critical of reasoning, including one's own.

But how does one evaluate validity in syllogisms? If I try and catch my own preferred strategy, I find that I almost invariably express the meaning of the premises in Venn diagrams, spatially representing the given sets as circles that are distinct, overlapping, include each other, etc. For example, I understand the classic syllogism about the mortality of Socrates, that I just mentioned, as a spatially expressed set (circle) of 'mortal entities,' containing a spatially expressed set of 'men,' with Socrates being one specimen of the latter set, and therefore as one specimen of the former set.



This is, of course, only the impression I get from personal experience, and anyone claiming that introspection revealed something else to them is just as right as I am. Still, the phenomenon of 'circling,' as I will call the use of Venn diagrams, whether in actual drawing or in 'the mind's eye,' seems to be widespread (Ford, 1995; Bacon, Handley, and Newstead, 2003; Khemlani, 2021). Reflecting on the premises and reflecting on necessitated conclusions *without* calling forth some version of circling seems to be the exception (Johnson-Laird, 2001). Furthermore, using such diagrams enhances subjects' performance in syllogistic reasoning (Sato and Mineshima, 2015).

This is remarkable from the point of view of cognitive science's dominant paradigm of *cognitivism*. Cognitivism claims that all cognitive performance is the result of the internal processing of symbolic entities called 'representations' (Thagard, 2018), and physically drawing spatial shapes such as diagrams surely isn't internal, and internal representations of such shapes don't seem to be purely symbolic (remember that symbols are only conventionally connected to what they're supposed to be about, and spatial shapes seem to be, well, spatial). Cognitivism's account of reasoning steers educators toward an approach in which the abstract rules of symbol processing are key, and away from drawing, moving, visualizing, etc. In this view, approaches to teaching logic that uses the body, movement, or artefacts, are misdirected.

But the phenomenon of circling raises doubts about such an account: how can using circles enhance reasoning skills? Either cognitivism has to grant the act of drawing to be part of the cognitive processing, or cognitivism will have to grant that internal, but *not* symbolic, representations are part of the cognitive toolkit. If the first option is chosen, cognitivism yields to a version of extended, or even enactive, cognition theory. If the second option is chosen, cognitivism accepts that -some- internal representations are not disconnected from the rest of the body, world, or action. Such representations must then be conceived as somehow *shaped* by our embodiment, meaning that the fact that we are creatures who experience life in a three-dimensional world has a profound influence on *how* we process syllogisms.

In this paper, I argue that our skill in syllogistic reasoning is based on a skill we are much more familiar with, namely, our skill in engaging with the spatial aspects of our lives. Our acquaintance with spatial relations, afforded by our body and our ability to move through a three-dimensional world, lies at the core of what seems to be a completely disembodied intellectual act. We circle, because we primarily (pre-reflectively) grasp syllogistic relations as spatial relations. It is only after reflection that we derive formal rules. Therefore, I argue that we should prefer an embodied account of syllogistic reasoning (Van Calcar, 2023a, Van Calcar, 2023b).[2] The embodied account also explains why using Venn diagrams as a pedagogical tool works, as many teachers know, and that using drawing, motion, visualization, etc. in teaching is *not* misdirected.

This paper first sketches cognitivism's account of syllogistic reasoning and the role of Venn diagrams. In Section 2 some reasons to distrust cognitivism and prefer an embodied account of syllogistic reasoning are offered. Sections 1 and 2 are quite technical, arguing for an embodied understanding of syllogistic reasoning. If the reader is primarily interested in the method I designed to teach this skill, they might skip these. In Section 3, I present an experiment I conducted to substantiate the paper's hypothesis. In Section 4, I give some pointers for using Section 3's setup as a teaching tool. Finally, I offer a short summary and discussion.

1. Cognitivist Accounts of Circling

Venn diagrams have been extensively studied and have intricate relations with fundamental issues in logic. However, Venn diagrams are, even to John Venn himself, primarily a pedagogical device (Verburgt, 2023), so we do not have to delve into the technical subtleties connected to logical analysis. With Venn diagrams, one expresses the premises as related sets and evaluates whether a stated conclusion is valid. At this point, it might be worthwhile to remember that validity is different from truth: to evaluate validity, we ignore the truth value of the premises, and focus on the relations between them. For instance, we should ignore the truth value of the premises of:

[1] 1. No human is a mammal,
2. All humans are mortal.

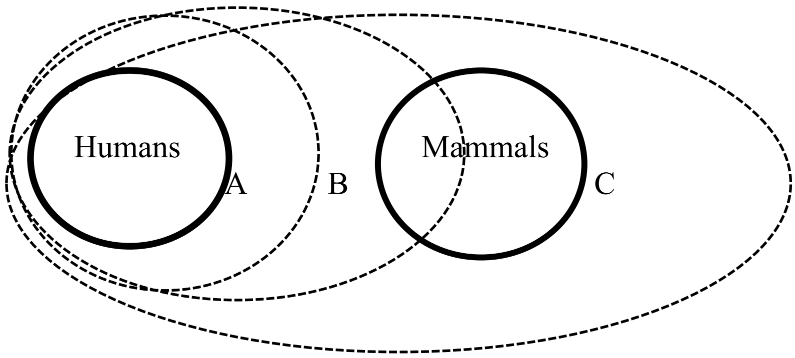
Therefore,

3. Some mammals are mortal.

[2] Van Calcar, M. "A Plea for Wild Philosophy: how thinking about online philosophy teaching shows that doing philosophy well is like being an elephant in the jungle." *Teaching Philosophy*, 46, 3 (2023a); Teaching Philosophy with LEGO." *Metodo* 11 (2023b).

and just look at their possible relation(s). 1. and 2. can be spatially expressed as in which A, B,

[1']



and C are the several possibilities afforded by premise 2. Conclusion 3. leaves out possibility A, in which premise 1. is satisfied (humans and mortals do not overlap, expressing that no human is a mammal), and premise 1. is also satisfied (all humans are contained by circle A, being mortal). However, no mammal is contained by A, suggesting the possibility that no mammal is mortal. That means that the conclusion is not *necessitated* by the premises, making the argument invalid, even if the conclusion is true.

So how would a cognitivist analyze the role of such diagrams in syllogistic reasoning? According to cognitivism, anything outside of the central nervous system can only be a source of input and arena for output. Using diagrams then is a kind of *epistemic action*, whereby one manipulates the world in such a way as to reduce cognitive load (called 'cognitive offloading').[3] In other words, diagrams are tools that alleviate the task at hand, by stabilizing information (mental 'grasping' of propositions is prone to shifts and errors), relieving the load on working memory, and thereby creating cognitive capacity for further -internal- processing. One can compare this to writing down a grocery list, or to a professional barkeeper that uses different glasses to remember the order he just got (Beach, 1993). The Venn diagrams are used as follows: the reasoner reads (or hears) the premises, encodes their content (information) into representations, processes these representations, and decodes the result of that processing in afferent signals that lead to the motor activity of drawing diagrams. The diagrams are, thus seen, expressions of internal cognitive processes, on a par with other motor activity. The drawings can then serve as available input, to be encoded, processed, etc. In other words, if all went well, the Venn diagrams are just translations of the premises and their interrelation in a new format. That such drawing enhances syllogistic skill is presumably an effect of the way the information is presented in this new format, being processed into a helpful, 'easier-to-digest', form (Bauer and Johnson-Laird, 1993; Tversky, 2001; Giardino, 2015; Jamnik, 2021).[4] It seems obvious how one

[3] This is explained in Cognitive Load Theory, a highly influential theory in the psychology of learning and education (Sweller, Ayres, and Kalyuga, 2011). The term 'epistemic action' was coined by Kirsh and Maglio (1994). It denotes a kind of action that alters the outside world in order to ease a cognitive (epistemic in their case) task.

[4] Encoding information into smaller units is called *chunking*. A reasoner might encode information into a different, 'lighter', format. One might, for instance, encode a string of numbers like 033120248 into birthdate (March 31st), current year (2024), and current age of oldest child (8). Thereby the reasoner relays part of the processing to long-

gets better at this; neuronal changes make for faster and more accurate processing, observable in faster and more accurate drawing of diagrams, and faster and more accurate further production or evaluation of syllogistic conclusions.

So, what happens when one doesn't draw, but somehow internally represents such diagrams? People who have had experience with drawing diagrams are known to visualize diagrams when tackling syllogisms, and, when skilled at this, to outperform those who don't (Sato and Mineshima, 2015). In trained reasoners, pen and paper seem to become redundant. A cognitivist assumes that the representation is an encoded symbolic version of the content of the premises. In that way it is not different in kind from the mental representations of any part of the world, factual or hypothetical. The visualized diagrams can, as representations, become part of cognitive processes, in the same way any representation can. Therefore, internal diagrams work -almost- as well as drawn diagrams. The experience taken from external drawing has caused neural changes, and those neural pathways make it possible for a reasoner to do without the external props.

However, if we allow diagrammatic representations to be part of proper cognitive processing, they cannot reduce cognitive load. Being mental representations, they do not stabilize information, or free up working capacity, because they are part of the processing itself. Adding such representations to the processing might even *add* to the workload, because they would be just *more* representations to process. This is a serious problem for cognitivism, because, without a solid argument on why using mental diagrams makes processing faster and more accurate, cognitivists haven't really explained anything. Stating that such use simply does enhance efficiency, is just another way of assuming the conclusion. The question is *how* and *why* an internal diagrammatic representation helps in deducing.

In the next section we will argue that this question cannot satisfactorily be answered by cognitivism, and that we should look at an embodied explanation.

2. Embodied Accounts of Circling

Cognitivism gets challenged by a family of theories, often referred to as theories on *4E-cognition* (with the E's standing for embedded, extended, embodied, and enactive), that claims that we cannot satisfactorily explain cognition without taking the environment, body, and action into account. It basically argues that only studying the brain to understand cognition is like only studying the boat's rudder to understand sailing. One of the most compelling arguments to distrust cognitivism comes from evolutionary considerations: humans have developed to efficiently deal with challenges, relying for a big part on their cognitive capacities. That means that human cognition is bound to be realized by bodily interactions with the world, making cognitivism's insistence on the brain's isolated processes quite idiosyncratic. It seems much more likely that the brain's activity is not some anomalous processing of detached symbols, but continuous with (processes in) the real world.

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term memory, reducing the load on short-term memory. However, it is far from clear how encoding information into spatial arrays is a form of chunking. Moreover, it does not explain *why* chunking would use *spatial* arrangements.

The E-family has had considerable success in giving descriptions and explanations of so-called *lower order* cognition. Instances of catching balls, finding the way to a museum, and using your fingers to count, can be accounted for without, or with a minimal role for, symbolic representations (McBeath et al., 1995; Clark and Chalmers, 1998; Dehaene et al., 1999). However, *higher order* cognitive phenomena, such as imagining, planning, and reasoning, are harder to constitutively connect to embodied action. Such phenomena seem, at first glance, to be thoroughly disconnected, and seem to exclusively take place in some internal realm of the mind. However, there *is*, at second glance, a constitutive (and thus not merely supportive) role for embodiment in syllogistic reasoning.

One of the members of the 4E-family is *Grounded Cognition Theory*. This theory argues that the stuff that realizes cognition, *concepts*, and thus the words we think with,[5] is rooted in sensorimotor experience. It thus argues against cognitivism's idea that representations are symbolic, detached from physical reality, or *amodal*:

> The core knowledge representations in cognition are *not* amodal data structures that exist independently of the brain's modal systems. Instead, according to a positive definition of grounded cognition—the environment, situations, the body, and simulations in the brain's modal systems ground the central representations in cognition. From this perspective, the cognitive system utilizes the environment and the body as external informational structures that complement internal representations. In turn, internal representations have a situated character, implemented via simulations in the brain's modal systems, making them well suited for interfacing with external structures. (Barsalou, 2010: 717)

A plethora of research has demonstrated this claim for concrete words, like action verbs and concrete nouns. Behavioral data, neuroimaging, somatotopic relations, corpus studies, Transcranial Magnetic Stimulation, etc., have shown that such words are inextricably bound to embodied experiences, and with embodied (re)actions (overviews in Barsalou, 2008; 2020; Pecher and Zwaan, 2010). On reading 'kick', for instance, cortices dedicated to the motoric act of kicking get activated (Hauk et al., 2004). The idea is that words associated with experienced action, or other sensorimotor experiences, reactivate the neural structures that were activated during the actual experience. The neural circuitry engages into a *simulation* of the experience.

Grounded Cognition approaches, like *Conceptual Metaphor Theory* (CMT), are even able to construe abstract concepts, like JUSTICE, as -at least partly- embodied. CMT argues that such concepts are based on concrete concepts through *metaphor*. We understand concepts of things that we haven't had any experience with, by mapping those onto the things we are familiar with, because we have had sensorimotor experience with the latter (Lakoff and Johnson, 1999; Lakoff and Nuñez, 2001). When we think about time, for instance, we use concepts about space. Time *goes by*, the future is *forward*, things happen *after* or *before* other events, etc. (Nuñez, 1999). By mapping TIME onto SPACE, we gain understanding of TIME through our acquaintance with SPACE. CMT demonstrates that we recruit so-called *image schemas*, concepts that are mostly

[5] Like most things worth thinking about in philosophy, the relation between words and concepts is debated. Let's forego this debate and accept the widely held conviction that words and concepts are intimately connected.

about spatial relations and movements, to deal with challenges that are not about space or movement. Image schemas function as structuring systems for other concepts (Grady, 1997). For instance, the image schema of CONTAINER enables thinking about people being IN a team, things being OUT of sight, and falling IN love. As Lakoff and Johnson write in their seminal *Metaphors We Live By*:

> [W]e typically conceptualize the nonphysical *in terms of* the physical – that is, we conceptualize the less clearly delineated in terms of the more clearly delineated. (Lakoff and Johnson, 2003: 59)

The *structure* of the 'more clearly delineated' is used as a matrix to map the 'less clearly delineated' upon, thereby deeply influencing the way we understand the latter.[6] CMT thus argues that the words we encounter, the concepts we process, and the ways in which we process these are grounded in our embodied lives. The question before us now is this: how would CMT explain syllogistic reasoning and the phenomenon of circling?

Engaging with premises, and drawing inferences from these, is obviously a matter of engaging with words and sentences. Contrary to cognitivism's account, these words and sentences do not get encoded into amodal representations, but they get encoded into *modal* representations (which means that they are somehow constitutively, instead of just causally, connected to, or shaped by, our sensory experiences).[7] They recruit cortical systems for kicking, seeing, touching, and moving in general, even if they have to go through some metaphorical mapping. To get a better idea of what actually happens (what 'the recruitment' of cortical systems in this context means), and to understand what circling has got to do with syllogistic reasoning, we'll have to take a closer look at what happens during reasoning tasks, according to psychological research.

Let us take [1], the syllogism we discussed in the Introduction as an example. A subject first gets to accommodate the first premise, "No human is a mammal." The subject will process the premise into some kind of representation. Second, the subject has to take the second premise and integrate that information into the representation of the first premise (Johnson-Laird 2001). Thirdly, and crucially, the actual reasoning part starts: what conclusion follows, if any? Taking CMT's cue, we can see how words like 'mammal,' and 'human' get encoded with concepts like MAMMAL and HUMAN. These are grounded, according to CMT, and sensorimotor systems are recruited for their processing. That explains why reasoners often report visualizing the

6 Gallese and Lakoff argue that the same neural networks involved in processing the source domain, are recruited to process the target (Gallese and Lakoff 2005). The source schema has a structuring influence on the target; the target gets molded into the format of the source (that is what 'mapping' means). Our understanding of the structure of space, for instance, molds our understanding of the structure of time, to the point that we cannot untangle TIME from its spatial schema. Because we recruit the neural circuitry created by, and for, embodied experiences to deal with concepts, we think, infer, manipulate, and process all concepts in an embodied way. Thinking about the passing of time is based on the same structure in which we think about space, with this latter structure thoroughly grounded in our bodily capacities and embodied experiences.

7 Unlike some of the more radical versions of 4E (e.g. Hutto and Myin, 2017), I condone the talk of 'representations', as long as we don't consider them to be things we can point at (cf. Zahnoun, 2021). More precisely, I agree with the criticism targeting the 'reification' of representations, turning them into entities that might be acceptable for any natural science, while they retain their magical semantics. In this paper, however, I have chosen to follow mainstream psychology, and liberally use 'representations', without claiming that I know what they precisely are supposed to be.

situation that is stated by the premises: concepts like MAMMAL are 'seen' in the mind, and the premises state a situation in which mammals and humans are seen as *distinct* groups (Bucciarelli & Johnson-Laird, 1999).

What happens in the third, essential, step? Even though some test subjects report using the rules of inference, and other test subjects report on 'seeing' the validity in the mental picture they have created, it can be argued that both reports do not report what happens on a more basic level. When people experience rule-following, they might be using some kind of formal operation, but it's hard to say what that actually looks like for a reasoner. How does one understand that humans and mammals are disjunct, for instance? This strategy also wouldn't explain the fact that some types of syllogism (for instance, categorical) are easier than other types (for instance, disjunctive). These types rely on the same number of rules. Reports on 'seeing' the scene, and being able to derive conclusions that way, are also highly unlikely. Markus Knauff has demonstrated that in such reasoning, visualization actually *impedes* reasoning performance (Knauff, 2013). This *visual impedance effect* is, in all likelihood, caused by working memory overload, caused by irrelevant visual details. It also doesn't concur with neurological findings. Fangmeier et al. found that during the first two steps visual areas are activated (along with memory-related areas), but that these cease all activity in step 3. In step 3 the posterior parietal cortex becomes active, especially those areas that are associated with dealing with spatial challenges (Fangmeier et al., 2006). Using Transcranial Magnetic Stimulation (in which the functioning of specific cortical areas is hampered), Hamburger et al. found that targeting the primary visual cortex (V1) caused people to reason *better* (Hamburger et al. 2018). In sum, reasoners don't reason by following logical rules, and they don't reason by manipulating imagistic representations.

Knauff and collaborators came up with an alternative explanation. The neurological data suggests that *spatial skills* are essential in step 3. Behavioral data suggest the same: concurrent spatial tasks impede reasoning, while concurrent visual, computational, or linguistic tasks, do not (Knauff et al. 2004). Knauff therefore develops the *Space to Reason Theory* (SRT. Knauff, 2013), which claims that reasoning is basically a *spatial* activity. Let's look at step 3 of evaluating [1] and see what happens according to SRT. When reasoners disjunct MAMMAL and HUMAN, they create a so-called *spatial layout.* Spatial layouts abstract away from irrelevant detail, but schematically structure the situation, based on the *relevant* features of the premises.[8] In other words, reasoners (unconsciously, because this happens in the parietal cortex, which is inaccessible to human consciousness) create a semi-abstract arrangement in which the stated situation is expressed by spatial relations. Semi-abstract sets MAMMAL and HUMAN are spatially separated from each other.[9] Evaluating the conclusion of [1] then requires a *spatial* judgement: the conclusion is a spatial overlap between MORTAL and MAMMAL. If such an overlap is necessitated by the premises (meaning that the spatial layout couldn't have been different), the conclusion is valid. Let's take [3], slightly more accessible than [1]:

[3] 1. All humans are mammals

[8] That irrelevant detail can get in the way, can be illustrated by adorning [1] with all kinds of adjectives. E.g. "None of the purple-haired humans is a furry and warm mammal. All creatures that are human, have ears, and that sometimes are furry and warm, can die. Therefore, some of the animals that have ears, are sometimes purple, but not furry and warm, are mortal."

[9] This is what a disjunction looks like, and probably is the only real phenomenological experience people can have when thinking about disjunct entities.

2. All mammals are mortal

Therefore

3. All humans are mortal

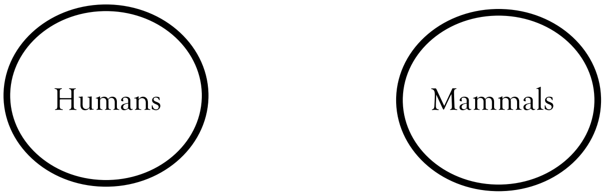
In tackling [3], a reasoner spatially arranges HUMAN to be a subset of MAMMAL, and MAMMAL to be a subset of MORTAL. Judging validity now becomes a matter of judging *containment*. The premises, as grounded propositions, thus recruit the cortical systems that also enable spatial skills, which are based on our extensive experience with containment. Looking back at the argument from evolution we discussed earlier, that makes sense: phylogenetically and ontogenetically, we learn to deal with three-dimensional space much earlier than we learn to deal with linguistically presented premises and conclusions (Godfrey-Smith, 1996). It is very likely that dealing with deducing is a case of *exaptation* (Gould and Vrba, 1982): evolutionary adaptation works too slowly to have created specialized structures for this job, so, as a matter of neural reuse, an existing structure was recruited to do the job (Anderson 2010). In exaptation the older structure typically influences the new function, much like what happens in CMT's mapping relations. Mark Johnson links this to a naturalized theory of language. This theory

> is based on the hypothesis that, over the course of evolutionary history, humans developed the capacity to recruit areas of the brain originally evolved for perception and motor activity for the purpose of "higher"-level acts of conceptualization, reasoning, and linguistic communication. Exaptation—the technical term for this type of process—is used to explain how embodied creatures could possibly acquire abstract thought and expression by making use of the body-based syntax and semantics of perception and bodily action. (Johnson, 2018: 634)

Our linguistic skills are realized by cortices that were adapted for dealing with being an embodied creature, living in a three-dimensional world, linking our concepts to embodied capacities, skills and experiences. Deducing is grounded in cortices that were adapted to deal specifically with space, and therefore deducing is infused with spatiality, and therefore syllogistic reasoning relies on spatial layouts.

So, what about the diagrams? We noticed that using diagrams enhances syllogistic skill, even when diagrams are 'merely' mentally manipulated. We also noted that cognitivism's explanation of this phenomenon, which is based on cognitive offloading, doesn't do the job it wants to be done. Let's look at an embodied account of physically handling Venn diagrams (usually by drawing). When a subject reads premise 1. from the example we discussed in the Introduction, "No human is a mammal", the contents get processed into representations of two sets, or groups. Premise 1 states that these groups, group HUMANS and group MAMMALS, are distinct, meaning that they do not overlap. 'Grouping' and 'overlapping' seem to be only figurative (metaphorical) ways of describing what happens, but the claim of this paper is that the premise actually gets encoded into a spatial format, that is, gets configured by image schemas into a quasi-abstract representation. The subject thus creates a spatial arrangement of two groups separated by space. When the subject draws [4], she expresses this internal layout.

[4]



When engaging in the second premise, she spatially includes HUMANS as a group *inside* a third, larger, group, namely group MORTAL. In doing so, she notices that the situation affords more than one spatial layout, as in possibilities A, B, and C we drew in the Introduction. We already saw that the indeterminacy of that example makes the offered conclusion invalid.

Cognitivism's account of circling when drawing might be just as good as the one offered above. Drawing diagrams might, after all, be a case of cognitive offloading. It is in the explanation of purely mental circling ('in the mind's eye') that cognitivism is less convincing. Cognitivism basically claims that people who have had some experience with drawing diagrams internalize this tool by visualizing the circles. In doing so, they get -at least some of- the effect of external tool-use on syllogistic skill. The embodied account turns the story around; circling isn't a tool to alleviate cognitive load, but understanding syllogisms *is* circling. Paying attention to visual imagery, or trying to follow rules of inference, merely distracts from the actual mechanism that enables us to tackle syllogistic tasks. Drawing is thus *not* a spatial expression of the processing of symbolic representations, but the outward expression of modal (i.e. spatial) processing. Circling is already part of the internal processing, and is therefore not something that one internalizes, but something one externalizes when actually drawing. The reported internal visualization of diagrams is therefore *effect* and does not *cause* syllogistic skill.

The phenomenon that experiences with physically using diagrams (i.e. by drawing) enhances syllogistic skill is caused by the structuring effect the experience has: experiencing spatial layouts in syllogistic tasks creates a -more or less- noise-free approach (Knauff, 2013). The sensorimotor experience activates the cortical systems dedicated to spatial activity directly, and thus creates neural pathways between linguistically rendered premises and spatial layouts. The experience affects the way one sets up a cognitive system: the more efficient such pathways, the more efficient the reasoner (see Lakoff 2014, for a non-technical description of the build-up of neural pathways as the substrate for metaphorical mapping).

In sum: the embodied account of syllogistic reasoning developed here argues that a reasoner tackles syllogistic tasks by recruiting systems that we also (and primarily) use for dealing with space. These systems influence our reasoning processes by molding them into a spatial format. The efficiency of such spatial formats can get impeded by distractions, but sensorimotor experience with spatial formats trains the reasoner in discerning relevant aspects. This accounts for the role of Venn diagrams in the enhancement of syllogistic skills.

Section 3 describes a test that I developed to look for the structural link between embodied experience and syllogistic performance. In Section 4, I discuss possibilities to use the setup of the test for teaching practices.

3. Testing Whether Enhanced Bodily Experience Enhances Syllogistic Performance

If the argument developed in this paper is right, and if conventional wisdom on training and practice is right, a richer (longer, or more intense, or multimodal) experience will yield more results. If we, therefore, enrich the bodily experience of engaging with Venn diagrams, we should further enhance syllogistic skills. If this is what we see, cognitivism will have a hard time explaining it. It would be hard to sustain that there's no constitutive role for embodiment if there is a structural link between embodied experience and syllogistic skill. To test this, I created cardboard circles that can be used as 3D Venn diagrams. Handling these will surely create a multimodal experience (visual, tactile) that should, if the embodied view is right, enhance performance more so than 'mere' drawing, because the reactivation of spatial skills will be stronger, and the neural pathways will get stronger.

We selected test subjects who are unlikely to have had experience with using diagrams in syllogistic reasoning, but who are cognitively advanced enough to be able to evaluate syllogisms. Our test subjects were therefore 3rd grade high school pupils, from pre-university level secondary education, at a school that intends to supply pupils with a broad intellectual education, including classical Greek and Roman languages and culture. This school also offers approximately 20% of the schedule's time to projects that are - mostly - not part of the compulsory curriculum. Getting introduced to syllogisms is thus embedded in the school's ambition and program. These pupils also haven't had any experience with syllogistic reasoning, as far as we know (it's not on the school's schedule in grades 1 to 3, and during the experiment none of the pupils gave any sign of having prior knowledge).

Test subjects: 77, average age 14 years old, approximately equally composed of male and female, predominantly native Dutch.
Location: pupil's own high school (Netherlands), 4 classrooms.
Date: June 23rd, 2023.

We told the pupils that we were giving them training in syllogistic reasoning. We labelled 4 groups, A, B1, B2, and C (24 in A, 15 in B1, 21 in B2, and 17 in C). We used their regular grouping (these groups are randomly created when entering 1st grade, by dividing the total number of new pupils into groups of roughly equal size. The difference between the numbers of pupils in these groups during the test was almost wholly caused by absentees). The 4 groups were separated and supervised by 4 qualified high school teachers. The test ran as follows:

Round 1

- Group A got to watch an instructional video on syllogisms (4 minutes), in which there is no mention of diagrams. The video focusses on discerning valid from invalid conclusions. The attendant teacher was instructed to refrain from suggesting diagrams, or any other technique. The subjects got several syllogisms to practice with, for 60 minutes, supervised by the attendant teacher. Then, they took Test 1, consisting of 10 syllogisms, with 3 invalid and 1 valid conclusion per syllogism offered, in a 10-minute frame.[10] They got to use a draft sheet. They ticked their answers on a multiple-choice response form.

[5] Examples Tests 1 and 2:[11]

Given: All bears are made of wood
Given: Some bears are sharp

- ○ All sharp things are made of wood
- ○ At least some sharp things are made of wood
- ○ No sharp thing is made of wood
- ○ No wooden thing is sharp

Given: No A's are B's
Given: No B's are C's

- ○ All A's are C's
- ○ No C is an A
- ○ Some A's are C
- ○ Nothing follows

- Group B1 and group B2 got to watch an instructional video on syllogisms (5 minutes), in which the use of Venn diagrams is explained. The video focusses on discerning valid from invalid conclusions. The subjects got several syllogisms to practice with, for 60 minutes, supervised by the attendant teacher. Then, they took Test 1. They got to use a draft sheet. They ticked their answers on a multiple-choice response form.

- Group C got to watch an instructional video on syllogisms (5 minutes), in which the use of the 3D Venn diagrams is explained. The subjects got sets of cardboard circles, and syllogisms to practice with, for 60 minutes, supervised by the attendant teacher. The cardboard circles were concentrically laser cut from thick paper (basically as thick as the machine can cut without seriously burning the paper; in our case we were satisfied with 120g paper). Their rims allow writing (to denote the set), come in different diameters (the A3-sheets they are cut from allow circles of up to 40 cm), and can be laid out in distinct, overlapping, or including patterns. Figure 1 illustrates the use of the circles (in this case a hand-cut version) for the valid "All men (mensen) are animals (dieren), All animals are mortal (sterfelijk), Therefore all men are mortal".

[10] The training set, Test 1, and Test 2 were created by randomly selecting (through an online bingo machine: https://basisonderwijs.online/digibordtools/bingo.html) 3x10 syllogisms from a large collection of syllogisms.
[11] This is a translation: the tests were taken in Dutch.

[**Figure 1**]

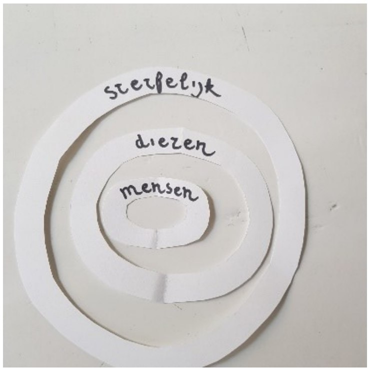
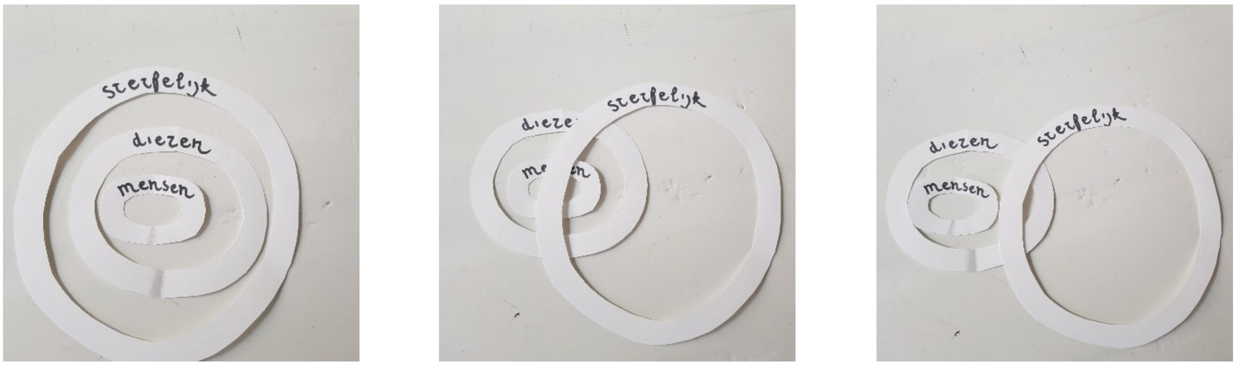


Figure 2 gives the three possible layouts of the invalid syllogism "All men are animals, some animals are mortal, therefore some men are mortal". Notice that the layout on the right shows the invalidity: the premises allow this third layout, therefore the conclusion does not follow of necessity.

[**Figure 2**]



The pupils in this group found out that they had to think about the sizes of the sets. Randomly assigning cardboard circles to sets created problems, as when, in above example, they assigned 'men' to a big circle, and 'animals' to a smaller one. As soon as they figured out how to use the correct sizes, they started to stack and slide the circles. After some practice, they could determine which layout(s) matched the premises, and, as several pupils said, they could 'see,' or 'read off,' whether the possibilities validated the conclusion. For instance, they pointed at the layout at the right of Figure 2 and stated that 'men' and 'mortal' do not *have to* 'overlap,' rendering the conclusion invalid. It seems as though they understood disjunction through the experience of circles that do not have a shared space.

After practice, they took Test 1. They got to use the cardboard circles. They ticked their answers on a multiple-choice response form.

An incentive was built in, the subject of the group who did best receives a prize (a bag of candy). Speed decided who won in case of a draw. This was mentioned at the beginning of Round 1.

Round 2:

- After a short break (10 minutes passed in the classroom to prevent communication between the groups), all test subjects took Test 2, consisting of 10 syllogisms, with 3 invalid and 1 valid conclusion per syllogism offered, in a 10-minute frame. They only got a response form, without being allowed to write or draw (it was made explicit that any marks other than name and ticked answers would render the test invalid). Incentive for all groups: the subject per group who made the most progress (as compared to Test 1) receives a prize (bag of candy). This was mentioned at the beginning of Round 2.

After the test all response forms were anonymized, and the results compiled and checked for the hypotheses.

We suspected that the format of the tests would influence the results: for group A, practice and Test 2 resemble Test 1, meaning that practice and Test 1 align with Test 2. For groups B1, B2, and C, Test 2 would be in a novel format, not aligned with practice and Test 1. We therefore suspected that group A would get better results at Test 2, and the other groups would, being deprived of their tools, get worse results. After all, it is unlikely that 60 minutes of practice and a 10-minute test will enhance skills enough to cancel this misalignment effect. Crucially, we hypothesized that group C would get worse results, but significantly 'less bad' than groups B1 and B2.

It turned out that group A indeed improved their average performance: the score (number of correct answers, out of the 10 requested) went up 0.67 points from Test 1 to Test 2. Group B1 scored worse on Test 2, by 0.87 points. Group B2 also scored worse on Test 2, by 1.19 points. These findings were in line with our expectations. However, group C's score went *up* on Test 2, by 0.71 points.

[6]

Group	Test 1	Test 2	Difference
A	6.13	6.79	0.67
B1	6.07	5.20	-0.87
B2	6.10	4.90	-1.19
C	6.06	6.76	0.71

At first glance, *unguided* teaching seems to be most effective. The group that didn't get any instruction, other than 'determine the validity', Group A, outperformed the other groups in both tests. However, as teachers know, groups develop their own dynamic, and Group A seems to be a more focused, and hence more successful group of pupils. Average grades (across all school subjects) in Group A (which is, as noted, a regular class) are approximately 0.6 points (on a 10-point scale) higher than grades in Groups B1, B2, and C. This would explain the results of Test 1. Group A also outperformed the other groups on Test 2, by improving their score by 0.67 points. However, if we take the misalignment effect into account, and see what that effect causes in Groups B1 and B2, we could add that score to Group C's score on Test 2. In other words, Group C's skills cancelled the misalignment effect, leading to affecting the most progress from Test 1 to Test 2. It might be argued that the 3D diagrams were 'less misaligned' than the 2D diagrams, but that would only contribute to the embodied account that this paper develops.

4. How Teachers Can Encourage Spatial Actions in Syllogistic Reasoning

If, as I've argued in the Introduction, teaching syllogistic skills is worth your pupils' while, the embodied (cardboard) system seems to offer an effective way of doing so. In this section, I will give some guidelines on how to use the cardboard system.

Preparation:

- Consider *your goals and your program*: how much time are you willing to spend on the honing of this skill? At this time, I haven't investigated whether the effect of the carboard circles lasts, but didactical wisdom tells us that training a skill should, ideally, be a prolonged, recurrent, or at least repeated, affair. Trying to organize such training might cause practical problems. Typical high school timeslots don't allow prolonged training sessions, so you might want to plan several sessions. This might also be the point at which to think about how much time you are willing to spend on teaching syllogistic skills. I started this paper with arguing that syllogistic reasoning is a good starting point to start honing reasoning skills, and that reasoning skills in natural language are the backbone of critical thinking. However, there is a curriculum at every school, and there simply isn't enough time to do everything. It might be argued that pupils learn reasoning skills when they're integrated into other subjects: applying them to the subject at hand makes those skills seem to be more relevant, and valuable time would be saved. However, making the training of syllogistic reasoning a distinct part of your program highlights it as a skill that can be applied to all kinds of reasoning challenges, instead of it being just applicable to the subject at hand. We are all familiar with the effects of compartmentalization in educational practices: transfer is hindered when the principles of the skill are not explicitly addressed (Billing, 2007). It seems advisable to devote at least some time to the explicit teaching and training of the key skill of syllogistic reasoning.

- It is required that your pupils have *a rudimentary grasp on what validity is* (and know how to distinguish it from truth; in my experience younger pupils find it hard, at first, to accept the validity of false conclusions). Teaching them how *to work with* validity is, of course, a matter of using the circles.

- Consider how many syllogisms you want them to tackle and decide on the number of *3D circles* per pupil. Note that they need a set of several (at least three) circles per syllogism. Anything circular that you can carry around by the dozens, and that's preferably reusable, will do. However, I tested several plastic circles (acrylic glass, among others), but ran into the problem that most plastics are sensitive to the solvents in (erasable) markers, and quickly become messy when (re)used. Besides having limited reusability, they're expensive (compared to paper), and quite heavy if you need a hundred or more. As said, I ended up using a laser cutter and paper to make a stack of circles. Whatever your material of choice, be sure to carry extra circles, because your pupils are bound to lose, mess up, or break a few.

- Find or create a *training set of syllogistic challenges*. They're quite easy to find online and can also be diligently constructed.[12] Once created or found, you might want to sort them in degree of difficulty (syllogistic modus, order in which premises are presented, with or without valid conclusions, counterfactual, abstract, etc.). You might want to use abstract items only, to make your training less dependent on world involving knowledge, and therefore more culturally inclusive.

- Decide on a *set-up*: do you want the pupils to cooperate, or to work alone? How many demonstrations are you going to use? How much guidance are you willing to provide? What do you plan to do when pupils prefer to indicate different strategies and tools?

Execution:

- As any teacher knows, making the *relevancy* of the task at hand explicit for the pupil helps in motivation. Showing that everyday life is rich in syllogistic reasoning and illustrate this with a score of common and recognizable mistakes, and maybe even with examples of bad and downright deceptive arguments. For older pupils, it might help to argue that academic success -partly- depends on reasoning skills, and that syllogistic reasoning is part of most formal assessments.

- Be sure to create a *safe* atmosphere: pupils might come to perceive your setup as an intelligence test. Stress that reasoning is a skill that one gets better at through practice.

- You could tell them about the theory behind the use of cardboard circles, but it will not further your goals, because the pupils cannot consciously activate spatial pathways in the parietal cortex. Tell them that working with the tokens improves reasoning skills, and that those skills carry over to reasoning without the tokens. *Demonstrate the use* by example.

[12] And, of course, you're welcome to my sets (in Dutch).

- If you have planned enough time, take a baseline test at the start, and a test at the end of your training session(s). This will provide extra motivation. It is highly unlikely that a pupil will do worse at the second test, and learners *enjoy progress*. If your training set allows it, creating short tests is quite easy, and pupils can easily score their own results.

- You might be able to plan another training session, and you might be able to point at syllogistic reasoning in your further curriculum. Both are highly advisable for *retention* of the enhanced skill.

5. Conclusion and Discussion

This paper has argued that a convergence of research shows that syllogistic reasoning is a spatial activity, even if such reasoning has traditionally been seen as rule-following or the manipulation of mental images. That suggests that priming the activation of spatial capacities should enhance syllogistic performance, and that such priming could be a way to effectively teach syllogistic skills. A pilot experiment, that was conducted to see if such a priming effect could be seen, pointed toward the viability of this paper's argument.

However, the results of the experiment should not be accepted unconditionally: the setup omitted a baseline test, and a test with 77 subjects has limited value. Other factors might have influenced the results: working with the cardboard circles created a cheerful atmosphere and having fun while learning could be a cause of improved results. What I called the 'dynamic' of groups might also have influenced the results: not all groups applied themselves in the same way, and their focus might have shifted between Test 1 and Test 2. There are doubtlessly more factors influencing the outcomes, causing noise for the interpretation. Still, the experiment, as something of a pilot study, seems to point at the viability of the embodied account of syllogistic reasoning. In cognitivism's view, the apparent fact that tackling syllogisms by handling three-dimensional circles enhances skill is hard to explain. Cognitivists view this skill as a disembodied skill, aimed at the manipulation of symbols. Therefore, lifting and stacking pieces of cardboard cannot contribute to such a skill, let alone *more so* than drawing on pieces of paper. However, the embodied view *can* elegantly explain the results of the test.

The argument and the experiment suggest that working with the 3D circles can be effectively used when teaching syllogistic skills. In Section 4, I've tried to sketch how embodied reasoning can be implemented in educational practices. However, the proof is in the eating of the pudding, and other attempts to apply the cardboard system might debunk both the argument for embodied reasoning, and the claimed value for teaching. I am, of course, very much hoping that colleagues will try out what I've sketched, and will find an effective tool for teaching, and, simultaneously, corroborate my argument.

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Address Correspondences to:
Menno van Calcar,
Erasmus School of Philosophy, Rotterdam
Email: vancalcar@esphil.eur.nl