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The Role of Instructional Material Type in Enhancing Pre-Service Primary Teachers' Spatial Skills: Concrete and Virtual Materials

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Abstract: The purpose of this study is to examine the effects of virtual and concrete materials on the development of spatial skills of pre-service primary school teachers within the framework of cognitive load theory. The study was conducted using a pretest–posttest control group experimental design, one of the quantitative research designs. In the experimental group, activities developed with digital tools designed by the researchers were implemented, while in the control group the same activities were carried out using concrete unit cube materials. During the implementation process, both groups were presented with a three-stage activity set. These stages consisted of drawing the views of structures built with unit cubes from different directions, creating isometric maps, and reconstructing the structure on isometric paper. Spatial visualization tests were administered to students before and after the activities; at the end of the experiment, a cognitive load scale and an instructional material motivation scale were applied to both groups to determine their cognitive load levels and motivation levels related to the material. At the end of the study, it was found that the spatial visualization scores of the experimental group using virtual materials improved significantly more; while no significant difference was found in motivation scores, this advantage stemmed from the fact that the virtual material significantly increased only the germane (learning-oriented) cognitive load without significantly increasing intrinsic or extraneous cognitive load.

Keywords: *Spatial Skills, Virtual Manipulatives, Concrete Manipulatives, Cognitive Load, Pre-Service Primary Teachers.*

1. INTRODUCTION

Spatial skill is the ability of an individual to mentally comprehend and organize the world around them. In the literature, this construct is approached under several closely related labels that converge on the same core idea, among them spatial thinking (National Research Council [NRC], 2006; Yakimanskaya, 1991), spatial sense (National Council of Teachers of Mathematics [NCTM], 1989), spatial reasoning (Battista, 2007), and spatial cognition (Sjölinder, 1998). Among the components gathered under this construct are imagining how an object appears from another angle and manipulating that object in the mind (Lohman, 1993). Lohman (1993, p. 3) defines spatial ability as “the ability to generate, retain, retrieve, and transform well-structured visual images.” No single componential structure has been agreed upon beneath this umbrella. Some researchers divide spatial ability into two elements as orientation and visualization (Battista, 1994) or relations and visualization

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(Pellegrino & Kail, 1982), while others expand it to three components, such as mental rotation, perception, and visualization (Linn & Petersen, 1985), or to five, adding spatial relations and spatial orientation as functionally distinct skills. In Burnett and Lane's (1980) formulation, the construct denotes an individual's capacity for organizing two- or three-dimensional objects mentally. This forms the basis of spatial visualization skill, as spatial visualization involves mentally rotating shapes, recognizing them from different perspectives, and mentally simulating the transformation processes of these shapes. Spatial visualization, moreover, shows the more consistent association with mathematics achievement, rather than spatial ability construed broadly (Fennema & Sherman, 1977; van Garderen, 2006). Thus, the present study isolates this component as its dependent variable, and the broader terms introduced above are used here strictly as background constructs rather than as interchangeable synonyms. Spatial skill also underlies students' recognition and interpretation of geometric relationships, as well as their modelling of three-dimensional objects. According to research, because spatial skill is a skill, it can be developed and improved through activities supported by concrete and virtual materials in school mathematics (Yurt & Sünbül, 2012).

In this regard, the instructional curricula implemented in Türkiye include learning outcomes related to spatial skills at different grade levels with primary school carrying the earliest and most direct emphasis for the population examined here. Grade 1 students are expected to determine the positions of objects (Outcome M.1.2.2.1), and Grade 4 students examine objects from different directions through isometric- and grid-paper representations of structures built with congruent cubes; a comparable emphasis continues at the middle-school level, where Grade 7 students draw and construct two-dimensional views of three-dimensional objects (Outcomes M.7.3.4.1–M.7.3.4.2). These outcomes are included both in the 2018 Mathematics Curriculum and in the Turkey's Century Education Model (Türkiye Yüzyılı Maarif Modeli) that began to be phased in 2024 (Ministry of National Education [MoNE]", 2018; MoNE, 2024).

The type of materials used during instruction is an important factor in acquiring or developing spatial skills (Yıldız & Tüzün, 2011). Various types of materials are utilized in mathematics teaching. These include virtual materials, concrete materials, and learning tools such as textbooks. Concrete materials are regarded as tools that make abstract or difficult-to-understand concepts more comprehensible, promote active student participation in class, and increase students' motivation. For example, a study by Akın, İlhan, and Çelik (2019) stated that the use of concrete materials increased students' interest in and success in mathematics. Digital technology tools appear to carry comparable benefits for mathematics teaching. Reviewing work at the primary school level, Akkuş and Gök (2024) reported that such tools raised mathematics achievement.

Similarly, Barın and Tabuk's (2023) research revealed that the use of additional instructional materials alongside textbooks reduced students' mathematics anxiety and improved their achievement. However, it is also indicated that each type of material affects cognitive processes differently in students and therefore provides benefits at different levels

(Sweller, 1994). Working memory, as Sweller (1994) reminds, is limited; how an instructional material is designed and presented therefore bears directly on learning efficiency, and a material ill-suited to the situation generates cognitive load of its own. Specifically, virtual materials for spatial constructs let learners rotate and reconstruct virtual unit cubes step by step, rather than requiring a single static image to be mentally rotated. This feature is expected to reduce extraneous load associated with imagining unseen transformations, while the requirement to actively align each reconstructed view with the target structure is expected to increase germane load by engaging schema-building for part-whole spatial relationships (Sweller, 1994; Sweller et al., 2019). Particularly in topics requiring abstract and multi-dimensional thinking skills, selecting the right type of material both supports the process of developing students' spatial skills and reduces unnecessary cognitive load, allowing cognitive capacity to be focused on learning outcomes (Yıldız & Tüzün, 2011).

Sweller (1988) describes cognitive load as the mental burden a learner carries while studying. Because information-processing capacity is finite, students draw on mental resources to varying degrees as they work through a given task. How much of that capacity a task consumes, and what this means for learning, is the question Cognitive Load Theory was framed to answer. Sweller (1988) distinguishes three types of load within the theory. Intrinsic cognitive load, the first, stems from how complex the to-be-learned content is; it varies with how familiar the student is with the topic, what prior knowledge they bring, and how difficult the material is (Kalyuga, 2009). Geometry and spatial problems illustrate the point, since concepts and objects there must be pictured mentally, demanding more of the student. Extraneous cognitive load, the second type, is tied instead to how the instructional material is presented.

Presenting material with unnecessary details or organizing it in a complex manner distracts students and negatively affects the learning process. This prevents students from efficiently processing information during learning. The third and final type, germane cognitive load, refers to the mental effort that students devote to the active learning process and covers their attempts to process new information by establishing meaningful connections with what they already know. Materials presented well, in particular, open room for deeper learning (Şahin, 2015). Furthermore, the type of these materials also determines how they shape students' learning processes and how they manage their cognitive load. Concrete and virtual materials, which are frequently used in school mathematics and examined from various angles in many studies, can each create different levels of cognitive load in students and can differently affect the development of spatial skills alongside spatial activities.

In instructional settings, concrete materials, physical objects with which students can interact directly, are frequently used as learning tools to concretize mathematical concepts and improve conceptual understanding (Gökkurt Özdemir et al., 2020). The use of concrete materials generally keeps extraneous cognitive load low because students have meaningful learning experiences through direct interaction with the material (Koparan & Özbey, 2018). However, concrete manipulation can itself introduce extraneous load through the physical demands of construction, the need to record intermediate steps on paper, and the transitions between the physical object and its two-dimensional representation. Even if a concrete material is simple in structure, the complexity of the activity in which it is used can also be a factor that increases intrinsic load. Concrete materials are particularly effective in developing spatial skills because they allow for direct observation and manipulation. However, the fact that concrete materials are mostly fixed and unchangeable does not always make it possible to present different and numerous models in learning activities where these materials are used (Özçakır & Çakıroğlu, 2022).

On the other hand, thanks to digital tools that are actively used in many areas of life today, virtual materials with interactive features that offer innovative opportunities in mathematics learning environments can be used effectively in learning processes. Virtual materials can lend the learning process a dynamic character, supplying visual and auditory stimulation to students. The software used in the present study relies primarily on visual and interactive features, dynamic transformation, multi-perspective viewing, and step-by-step reconstruction, and does not include an auditory component. As stated in the literature, these materials enable more concrete experience of abstract concepts and allow students to more easily visualize concepts mentally. At the same time, these materials allow students to adjust their own learning pace, thereby keeping extraneous cognitive load manageable. Their dynamic nature also helps students hold attention on learning itself while keeping cognitive load in balance. Such interactive features render learning more efficient and carry students' conceptual understanding deeper (Özdemir & Özçakır, 2019).

However, overuse or overly complex structures of virtual materials can increase cognitive load. Especially for students who are not accustomed to new technologies, the use of virtual tools can create additional cognitive load (Özbay & Seferoğlu, 2023). Therefore, complex and highly stimulating digital environments can cause students to lose their focus on learning by distracting their attention. The intense visual and auditory components of virtual materials may create unnecessary cognitive load in some students, leading to stimulus overload and attention distraction (Skulmowski & Xu, 2022). Furthermore, the spatially separated presentation of information sources can lead to unnecessary expenditure of cognitive resources due to the split-attention effect, thereby reducing learning efficiency (Chandler & Sweller, 1991). In effective instructional materials, such cognitive load elements should be minimized so that the learner's working memory is directed toward meaningful learning processes (Dervić et al., 2019). In this context, designing instructional materials consistently with mathematical concepts, in an organized manner, and with consideration of cognitive architecture is a decisive factor that increases the efficiency of learning processes (Mayer, 2024). Consequently, investigating the effects of concrete and virtual materials on cognitive load, and observing the potentially adverse effects of the complex and multi-sensory aspects of virtual environments, will enable more effective and efficient material designs in instructional processes. In this way, the effective use of cognitive architecture in material selection can positively support learners' attention and information processing.

Prior research has approached these constructs separately rather than jointly. Karakuş and Peker (2015), working with pre-service primary teachers, set dynamic geometry software against physical manipulatives and assessed outcomes with the Purdue Spatial Visualization Test and the van Hiele Geometry Test; cognitive load and material-use motivation remained outside their design. Kurban (2024) placed pre-service teachers' spatial visualisation development on Cognitive Load Theory ground, yet in a qualitative case study of four participants, with no material-type comparison. Tiwari and Bhagat (2024) measured both spatial visualisation and cognitive load with validated instruments while comparing augmented-reality modalities against traditional instruction, but with first-year engineering students rather than teacher candidates, and without a motivation measure. To our knowledge, no study has jointly examined material type (concrete vs. virtual), spatial visualization, multidimensional cognitive load, and material-use motivation within pre-service primary teacher education. Furthermore, examining the effect of these materials on the development of students' spatial skills in this process emerges as an important research need both for improving the quality of instructional activities and for student-centered material design. Since teachers and pre-service teachers participate in the design and implementation stages of instruction and act as designers of learning environments, revealing their perceptions of materials is also considered important. This study was therefore designed to examine how pre-service primary school teachers' material-use motivation and differing material preferences bear on their spatial skills during activities that involve spatial concepts, together with the cognitive load levels experienced throughout.

To this end, the relationships among the type of material used, the pre-service teachers' spatial skills, cognitive load levels, and motivation toward the material were examined in this study. The experimental group worked with virtual materials; the control group, with concrete materials. In line with this purpose, the following sub-problems were formulated to guide the study:

RQ1. Is there a statistically significant difference between the spatial visualization test gain scores (posttest – pretest) of the experimental group and the control group?

RQ2. Is there a statistically significant difference between the groups in terms of total scores and sub-dimension scores (Attention-Relevance; Confidence-Satisfaction) on the Instructional Materials Motivation Scale?

RQ3. Is there a statistically significant difference between the groups in terms of sub-dimension scores (intrinsic, extraneous, and germane load) on the Cognitive Load Scale?

2. METHODOLOGY

The study focused on what concrete and virtual instructional materials contribute to the spatial skills and cognitive load levels of pre-service primary school teachers. Its design was a pretest–posttest experiment with a control group, situated within the quantitative tradition. A design of this kind lets the instruments be administered to both groups before the intervention and again afterward, so that intervention effects can be weighed comparatively (Creswell, 2014). In addition, measuring participants' motivation toward the material at the end of the implementation process made it possible to examine the effects of the instructional materials on the learner from more than one aspect.

2.1. Participants

The study population comprised the third-year pre-service teachers who were enrolled in the Primary School Teaching Program at the Faculty of Education of Alanya Alaaddin Keykubat University and who were taking the "Mathematics Teaching" course in the 2025–2026 academic year (N = 58). Among this population, 36 students volunteered and gave written informed consent, forming the sampling frame of the study. Random assignment was carried out at the individual level, so that each of the 36 volunteers was placed into either the experimental group (n = 19) or the control group (n = 17) by means of a random number generator. In terms of demographic characteristics such as gender, age, and academic achievement level, the two groups showed a comparable structure, and 17 of the participants were female while 19 were male.

2.2. Data Collection Instruments

Data collection in this study relied on three separate instruments. The spatial visualization skills of the participants were measured with the Spatial Visualization Test (SVT), which consists of 32 items and asks the test taker to visualize three-dimensional structures mentally, rotate them, take them apart and put them back together, and estimate their appearance from various angles. The test was developed by Lappan et al. (1989) within the Middle Grades Mathematics Project (MGMP) at Michigan State University, and it was adapted into Turkish by Dursun (2010). Studies in the field generally treat the SVT as a sound indicator of spatial thinking skills and, in particular, of the ability to mentally rotate three-dimensional objects. On the validity side, Ben-Chaim et al. (1988) reported a correlation of 0.66 between the SVT and the Differential Aptitude Space Relations Test in a sample of 8th–12th grade students and interpreted this value as a high correlation according to Cohen's (1988) criteria. Cronbach alpha values between 0.72 and 0.86 have likewise been reported for the test, values that Nunnally and Bernstein (1994) regard as acceptable. In the present study, the Cronbach's α coefficient was calculated as 0.77, which is consistent with these earlier reports, and the SVT was accordingly considered a reliable and valid instrument for this study. Although the test was originally prepared for middle-grade students, the Turkish adaptation study was conducted with pre-service teachers rather than school-age students (Dursun, 2010), and later applications with large pre-service teacher samples did not point to any ceiling or floor effect; for example, Erkek et al. (2017) reported a mean score of 18.71 out of 32 (SD = 6.31, N = 1,007) together with statistically significant differences across undergraduate programs, which shows that the test preserves an adequate level of difficulty and discrimination for this population.

Motivation regarding the instructional materials was measured with the Instructional Materials Motivation Scale. Kutu and Sözbilir (2011) developed this 24-item instrument, rated on a 5-

point Likert scale, to gauge students' interest in a material, its perceived usefulness, and the degree of engagement it invites during learning. In the adaptation study, exploratory factor analysis pointed to two sub-dimensions, "Attention-Relevance" and "Confidence-Satisfaction"; Cronbach's alpha was reported at 0.79 and 0.69 for the sub-dimensions and 0.83 for the whole scale (Kutu & Sözbilir, 2011). High reliability has also been documented elsewhere: one study obtained 0.92 for the full scale, 0.86 for "Attention-Relevance," and 0.82 for "Confidence-Satisfaction" (Öngör, 2022). The scale has thus proven dependable across disciplines and educational levels. Within the present sample, Cronbach's α reached .93 for the total scale and .87 for each of the Attention-Relevance and Confidence-Satisfaction subscales, confirming adequate internal consistency within this sample.

Students' cognitive load experienced during the implementation process was measured using the three-dimensional Cognitive Load Scale developed by Dönmez et al. (2022). The scale consists of a total of 13 items that separately assess three sources, intrinsic, extraneous, and germane load; in the development study, exploratory factor analysis (maximum likelihood) explained 58% of the total variance, and the internal consistency coefficients of the sub-scales were reported above .81. The construct validity of the scale was confirmed in both online and face-to-face learning contexts. In the present study, Cronbach's α coefficients were .77 for the Intrinsic Load subscale, .85 for the Extraneous Load subscale, and .72 for the Germane Load subscale.

In this study, the Spatial Visualization Test was used to examine changes in participants' spatial visualization skills before and after the instructional intervention, while the other scales were applied at the end of the implementation and the effects of the difference in material type were examined.

2.3. Implementation Process

The study was conducted over a three-week period. Before the implementation, the Spatial Visualization Test was administered as a pretest to both groups and their initial levels were determined. The implementation process was carried out in three sessions. In these sessions, both groups engaged in three types of activities pursuing the same learning objectives: (i) examining three-dimensional structures built with unit cubes from different angles and supporting mental rotation processes, (ii) building given target structures through analysis and reconstruction and questioning part-whole relationships, and (iii) producing bird's-eye views and isometric representations of the constructed structures and discussing the mappings between these representations. The experimental group interactively conducted the activities in a computer laboratory through software developed by the researchers (Figure 1).

Figure 1. *Experimental Group Implementation Environment*

The software provided an interface allowing the visualization of dynamic transformations with virtual unit cubes, examination from different perspectives, and the step-by-step reconstruction of structures; thereby systematically supporting participants' mental imagery and spatial reasoning processes (Figure 2). The software interface reproduced the manipulative logic of the physical unit cubes used by the control group within a digital 3D environment, rather than introducing a gamified or scoring-based mechanic. Participants interacted with the software through two basic construction modes, "Add Cube" and "Delete Cube," and with these two modes they built and modified three-dimensional structures on a fixed grid. Beyond this, the interface carried direct view-switching buttons for the front, back, left, right, top, and bottom views, a toggle between perspective and orthographic projection, colour coding for the cubes, and a grid-lock feature that held every cube in exact alignment during construction. There was also a "reset/home view" option, so a participant could return to the opening viewpoint whenever needed. Save and load functions allowed the current state of a structure to be stored and taken up again in a later task. The software, on the other hand, contained no automated scoring, no correctness feedback, and no performance logging; the tool was meant to reflect the logic of hands-on manipulation, not to guide participants algorithmically. For this reason, participants' spatial visualization performance was evaluated outside the software, with the paper-based Spatial Visualization Test only. The software is publicly accessible at https://bilalozcakir.com.tr/materyaller/kup.html.

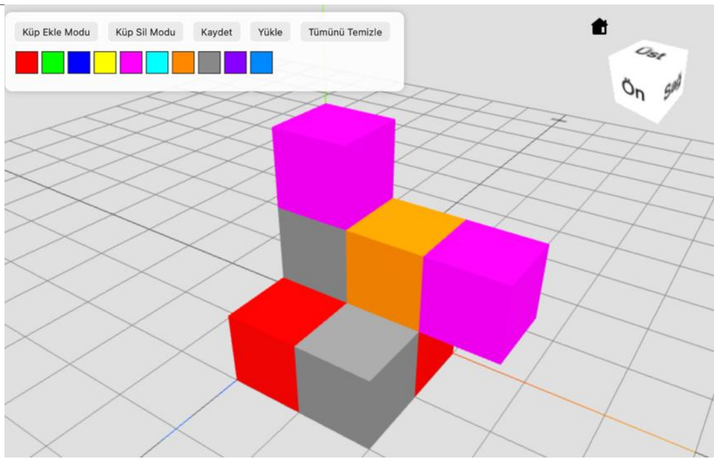

Figure 2. *Experimental Group Software Interface*

The control group carried out the same activity sequence in the classroom using concrete unit cubes (Figure 3); they performed the tasks of building structures with physical materials, estimating views from different directions, and producing bird's-eye/isometric drawings under teacher guidance (Figure 4). In both groups, the instructions were standardized, the sequence and duration of the activities were matched, and the task content was kept parallel; in an effort to reduce the potential influence of variables other than material type.

Figure 3. *Control Group Materials*

Before the implementation, an "activity booklet" prepared separately for each condition was presented to the participants. The booklet included a brief introduction to the use of the relevant material (virtual software or concrete cubes), objectives and learning outcomes, step-by-step instructions for the activities, and examples of expected products. In addition, a sample activity showing how the material was to be used was included with visuals for each group: for the experimental group, sample structure–transformation schematics on screenshots from the software interface; and for the control group, photographs of sample structures built with physical cubes and the corresponding isometric drawing examples were included in the booklet. These visual examples were explained through a brief introductory activity before moving on to the measurement phase; the introduction was kept in scope sufficient only to clarify tool use, in a manner that would not directly teach the target skill in either group.

Figure 4. *Control Group Implementation Environment and Material Demonstration*

Posttest administrations were carried out with all participants at the end of the third week. In this stage, the Spatial Visualization Test was applied once again and the changes in spatial skills were evaluated, participants' interest in the material, the usefulness they perceived, and their engagement were measured with the Instructional Materials Motivation Scale, and their subjective evaluations of the intrinsic, extraneous, and germane load dimensions were collected with the Cognitive Load Scale. All of these measurements were completed in a single session with standardized instructions, and the environmental conditions, the durations, and the order of administration were kept equivalent for the two groups during the whole data collection process. In this way, the effects of the intervention could be compared between the material types under conditions that preserved the internal validity of the study.

2.4. Data Analysis

Before the inferential analyses, the assumptions underlying each test were examined. Normality was tested with the Shapiro-Wilk test, separately for each group and each dependent variable, and the results came out non-significant in every case ($p > .05$). Still, these results were interpreted with caution: a non-significant Shapiro-Wilk result does not provide positive evidence for normality, and with group sizes of $n = 19$ and $n = 17$ the power of the test against real deviations from normality is rather limited. Skewness and kurtosis values stayed inside the ±2 band for all variables, a range commonly taken as a sign of approximate univariate normality. The homogeneity of variance was examined with Levene's test. Since the assumption of equal variances was not consistently satisfied for all dependent variables, Welch's independent samples t-test, which adjusts the degrees of freedom according to unequal variances and remains robust under these conditions, was preferred for all between-group comparisons. For the within-group comparisons from pretest to posttest, paired-samples t-tests were applied to the gain scores, whose normality was confirmed in the way described above.

Effect sizes were reported with Cohen's d, the analyses were conducted in the Jamovi program, and the significance level (α) was set at .05 for all tests

2.5. Ethical Approval

This study was conducted in accordance with the ethical principles outlined by the Alanya Alaaddin Keykubat University Scientific Research and Publication Ethics Committee for the Field of Educational Sciences. Ethical approval was granted unanimously under Decision No: 2026/06 (January 10, 2026). All participants were informed about the purpose of the study and voluntary participation was ensured throughout the process.

3. FINDINGS

The sample of the study consists of 19 participants in the experimental group and 17 in the control group. First, the pretest and posttest administrations of the Spatial Visualization Test for both groups were examined, followed by a report on the motivation and cognitive load outcomes associated with the material used.

3.1. Findings Related to the Spatial Visualization Test

When the Spatial Visualization pretest means of the groups were examined, they were found to be relatively close to each other ($\bar{X}_{exp}$ = 18.74, $\bar{X}_{cont}$ = 18.82). Whether the observed difference between the groups before the intervention constituted a statistically significant difference was examined using an independent samples t-test. According to the analysis, this observed difference was found to be statistically non-significant ($t(33.67) = -0.046$, $p = 0.964$). This indicates that the groups were not at different levels in terms of spatial performance before the intervention.

When the Spatial Visualization posttest scores of the groups were examined, both groups' posttest means were found to have increased. This increase was also found to be more pronounced in the experimental group (Experimental: $\bar{X}_{pre}$ = 18.74, $\bar{X}_{post}$ = 21.95, $\bar{X}_{diff}$ = 3.21; Control: $\bar{X}_{pre}$ = 18.82, $\bar{X}_{post}$ = 19.35, $\bar{X}_{diff}$ = 0.53). The significance level of the difference between the change scores across groups was compared using an independent samples t-test (Table 1).

Table 1. *Spatial Visualization Test (Post–Pre) Change Scores*

Group	n	Mean-Diff	SD	t	df	p	D
Experimental	19	3.21	3.03	2.081	27.68	0.047	0.71
Control	17	0.53	4.47				

In light of the analyses conducted, the increase in the experimental group was found to be significantly higher ($t(27.68) = 2.081$, $p = 0.047$, Cohen's $d \approx 0.71$). The findings indicate that virtual material-based activities were associated with a greater gain in spatial performance, 95% CI for the mean difference [0.04, 5.32]. The effect size was in the medium-to-high range (Cohen's d = 0.71, computed from pooled standard deviations; 95% CI [0.04, 1.38]), though the lower bound of both intervals lies close to zero and warrants a cautious interpretation given the sample size.

Paired-samples t-tests, run separately for each group, examined the within-group changes. From pretest to posttest the experimental group improved significantly in spatial visualization (diff = 3.21, SD = 3.03; $t(18) = 4.62$, $p < .001$, Cohen's $d = 1.06$), a large within-group effect. The control group's change, by contrast, did not reach significance (diff = 0.53, SD = 4.47; $t(16) = 0.49$, $p = .632$, Cohen's $d = 0.12$); engagement with the concrete material-based activities by itself, it appears, yielded no dependable improvement in spatial visualization.

3.2. Findings Related to the Instructional Material Motivation Scale

To examine the effect of the two different learning tools in the study on students' motivation, the Instructional Materials Motivation Scale scores were compared using an independent samples t-test (Table 2).

Table 2. *Instructional Material Motivation Scale Scores*

IMMS	Group	n	Mean	SD	t	df	p
Total	**Experimental**	19	4.06	0.45	1.119	27.15	0.273
	Control	17	3.84	0.68			
Attention-Relevance	**Experimental**	19	4.14	0.51	0.969	29.29	0.341
	Control	17	3.94	0.69			
Confidence-Satisfaction	**Experimental**	19	3.99	0.47	1.130	26.83	0.269
	Control	17	3.76	0.72			

When motivation scores were examined by groups, the experimental group showed relatively higher motivation ($\bar{X}_{exp} = 4.06$, $\bar{X}_{cont} = 3.84$). In the sub-dimensions of the scale, the experimental group displayed higher means in Attention–Relevance ($\bar{X}_{exp} = 4.14$, $\bar{X}_{cont} = 3.94$) and Confidence–Satisfaction ($\bar{X}_{exp} = 3.99$, $\bar{X}_{cont} = 3.76$). However, the analyses showed that these differences were not statistically significant (overall scale mean: $t(27.15) = 1.12$, $p = 0.273$; Attention–Relevance: $t(29.29) = 0.97$, $p = 0.341$; Confidence–Satisfaction: $t(26.83) = 1.13$, $p = 0.269$). Therefore, although motivation was quantitatively and relatively higher in the experimental group, significant differences were not observed. Effect sizes (Cohen's d, computed from pooled standard deviations) with 95% confidence intervals were: Total scale, $d = 0.39$, 95% CI [-0.27, 1.05]; Attention-Relevance, $d = 0.33$, 95% CI [-0.33, 0.99]; Confidence-Satisfaction, $d = 0.38$, 95% CI [-0.28, 1.04]. All group means fell in the upper portion of the 5-point scale (3.76–4.14), consistent with a possible ceiling effect.

3.3. Findings Related to the Cognitive Load Scale

To examine the effect of the concrete and virtual materials applied in the study on students' cognitive load perceptions, an independent samples t-test was conducted. The analysis was evaluated across the three sub-dimensions of the Cognitive Load Scale (CLS): Intrinsic, Extraneous, and Germane load; as the scale's developers do not recommend computing a total score (Dönmez et al., 2022) (Table 3).

Table 3. *Cognitive Load Scale Scores*

CLS	Group	N	Mean	SD	t	df	p
Intrinsic	**Experimental**	19	3.08	0.30	0.172	30.00	0.865
	Control	17	3.06	0.39			
Extraneous	**Experimental**	19	2.35	0.74	-0.901	32.76	0.374
	Control	17	2.54	0.54			
Germane	**Experimental**	19	3.65	0.24	2.174	25.62	0.039
	Control	17	3.41	0.39			

Note. Effect sizes (Cohen's d, computed from pooled standard deviations) with 95% confidence intervals were: Intrinsic, d = 0.06, 95% CI [-0.60, 0.71]; Extraneous, d = -0.29, 95% CI [-0.95, 0.37]; Germane, d = 0.75, 95% CI [0.07, 1.43]. Because the scale's developers do not recommend a total score (Dönmez et al., 2022), no correction for multiple comparisons across the three subdimensions was applied; this is noted as a limitation below.

In the analyses, Germane load was statistically significantly higher in the experimental group with a large effect size ($\bar{X}_{exp}$ = 3.65, $\bar{X}_{cont}$ = 3.41; t(25.62) = 2.17, p = .039, Cohen's d ≈ 0.75). No difference was observed between the groups on the Intrinsic sub-dimension ($\bar{X}_{exp}$ = 3.08, $\bar{X}_{cont}$ = 3.06; t(30.00) = 0.17, p = .865). In extraneous load, the control group's mean appeared relatively higher, but this difference was not statistically significant ($\bar{X}_{exp}$ = 2.35, $\bar{X}_{cont}$ = 2.54; t(32.76) = -0.901, p = .374). Participants in the virtual-material group reported higher germane load on the post-intervention self-report measure without causing any additional increase in extraneous (irrelevant) load in particular.

Overall, according to the analyses conducted in the scope of spatial visualization scores, motivation toward the instructional material, and cognitive load sub-dimension scores, the groups did not differ in terms of Spatial Visualization scores at the outset. After the implementation, the experimental group's increase in Spatial Visualization scores was found to be significantly higher. In motivation, the experimental group showed relatively higher means on all measurements, but these differences were not statistically significant. In terms of cognitive load, no significant difference was found in intrinsic or extraneous load; however, the germane sub-dimension showed a significant difference in favor of the experimental group. In general, while virtual materials improved spatial performance, they also strengthened learning-contributing processing (germane load), doing so without significantly increasing intrinsic or extraneous load.

4. RESULTS AND DISCUSSION

This study aimed to examine the effect of the type of material (concrete/virtual) used by pre-service teachers in activities involving spatial concepts on spatial visualization, motivation, and cognitive load. Particularly regarding which cognitive processes are activated by which material during the teaching of spatial skills in school mathematics, and how students' tendencies to use these materials and the cognitive load they experience interact; this constitutes a critical gap from the perspective of instructional design and student-centered material development. Considering that teachers and pre-service teachers play an active role in the design and implementation of instruction, evaluating their perceptions of materials and the relationships of these perceptions with performance in a holistic manner is of particular importance. Moreover, since pre-service teachers serve not only as learners in this study but also as prospective designers of learning environments, the way they experience and evaluate instructional materials is particularly consequential: their firsthand exposure to virtual manipulatives during training may directly shape the material choices they make in their own future classrooms (Gökkurt Özdemir et al., 2020).

According to the findings, the activities carried out with virtual materials produced a significant gain in spatial performance; the increase observed in the motivation of the pre-service teachers who worked with this material, however, did not reach statistical significance. No significant difference was found between the groups in intrinsic or extraneous cognitive load either. Virtual manipulatives give the user dynamic control together with several simultaneous representations, and complex spatial operations such as mental rotation can thus be externalized (Moyer-Packenham & Westenskow, 2013; Sarama & Clements, 2009). The interactive structure and the instant feedback of these materials also lessen the need for candidates to hold spatial relations and geometric transformations purely in the mind, so abstract concepts gain a more concrete character (Hegarty, 2004; Tversky et al., 2002). Considered within the framework of Cognitive Load Theory, the results point to an important distinction. Intrinsic load did not differ between the groups ($p = 0.865$), which shows that both material types preserved the difficulty belonging to the nature of spatial problem solving. The externalization opportunity of the virtual material, however, released working memory resources that would otherwise go to the mental processing of this difficulty. Mayer's (2024) multimedia learning principles offer another way to read this finding: the software presented spatial structures through dynamic visual channels and, at the same time, through interactive manipulation, creating a kind of dual-channel processing that static physical objects can hardly provide. Furthermore, the structure itself, its projected views, and the transformation process all met within a single interface, and this integration may have weakened the split-attention effect described by Chandler and Sweller (1991); working memory resources could then go to the learning target rather than to the work of combining separate information sources.

That the concrete material condition showed no significant within-group learning also deserves attention. Concrete materials, as the literature notes, generally support conceptual understanding well because they offer direct sensorimotor experience (Koparan & Özbey, 2018); yet being fixed and non-transformable, they run into representational limits in tasks that call for dynamic perspective taking (Özçakır & Çakıroğlu, 2022). In the present study, participants working with concrete unit cubes had to handle three things at once, building the structures physically, rotating them mentally, and producing isometric drawings on paper, and this may have forced them to spread their cognitive resources over task demands that were not integrated with one another. Such a situation fits the split-attention effect (Chandler & Sweller, 1991), where information sources separated in space or in time bring extra processing costs even when the total load seems moderate. The control group's extraneous load scores, slightly but not significantly higher ($\bar{X}$ = 2.54 vs. $\bar{X}$ = 2.35), support this reading; concrete material-based spatial activities may carry a hidden representational cost, one that global load measures miss although it still competes with germane processing.

The within-group analyses strengthen this interpretation further. The between-group comparison had already shown a significantly larger gain for the experimental group; the paired-samples t-tests added one more layer of evidence, since the experimental group improved from pre-test to post-test to a degree that was both statistically significant and practically large (d = 1.06) while the change in the control group stayed small and non-significant (d = 0.12). An asymmetric pattern of this kind, meaningful learning on one side and limited gains on the other, suggests that the difference between the two groups is more than a simple difference in gain amount. This result is in line with the argument of Yurt and Sunbul (2012) that the development of spatial skills depends on the quality of the engagement mediated by the material and not simply on experience to the tasks. Although the task content and the duration were equivalent in the two conditions, the concrete material condition appears to have lacked the representational flexibility that virtual environments provide. As Moyer-Packenham and Westenskow (2013) demonstrated, virtual manipulatives offer learners dynamic and transformable representations that static physical objects cannot replicate, and it is precisely this dynamic quality that may explain the large within-group effect observed in the experimental group. When the between-group and within-group findings are evaluated together, it can be said that spatial activities based on virtual materials produced reliable and substantial learning gains within a short instructional period, while comparable activities based on concrete materials did not. This advantage may be especially important for pre-service teachers, whose spatial skills are still developing during university education (Yıldız & Tüzün, 2011). Teacher candidates benefit most from instructional formats that support the construction of spatial schemas instead of assuming that such schemas already exist, and virtual environments seem more suitable for providing this support within a brief intervention.

Furthermore, the fact that germane load was significantly higher in the pre-service teachers working with virtual material is noteworthy. It is understood that these freed cognitive resources enabled the interactive, dynamic, and multi-representational presentations of the virtual instructional material used to strengthen processes that directly contribute to learning, such as schema construction and conceptual organization, while succeeding in doing so without increasing the extraneous load that unnecessarily complicates the process. In other words, working with virtual materials encouraged more effective cognitive work rather than more cognitive processing in completing spatial tasks, creating a situation consistent with the increase in spatial achievement. Sweller et al. (2019) hold that effective instructional design keeps intrinsic load, which is inherent to the subject, under control; strips away the extraneous load generated by distracting, off-topic elements; and thereby frees germane load, the cognitive resource devoted to forming and automating mental schemas. The absence of a difference in extraneous load in this study supports this situation. This situation demonstrates that the virtual material used in the study supported the learning process without increasing extraneous load; that is, without causing unnecessary mental effort such as interface complexity or technical difficulties. Because the material behaved dynamically and interactively, each solution step of a spatial problem became more explicit, and candidates' cognitive resources shifted from "how do I do this?" to "what am I learning?", toward construction and the making of deep meaning. Kalyuga (2009) further specifies that this optimization of cognitive resources is especially pronounced when learners possess sufficient prior knowledge to interact with the material productively but not enough to make the scaffolding redundant; a condition that aptly describes the current sample of third-year pre-service teachers encountering structured spatial tasks for the first time in a formal instructional setting. Since the virtual interface kept the transformation steps visible and reversible, the tool appears to have remained at a level that was demanding enough to support schema construction but structured enough to prevent cognitive overload.

The motivation findings, on the other hand, fit a ceiling pattern. Motivation scores were uniformly high in the two groups (means of 3.76–4.14 on a five-point scale); pre-service teachers evidently found the virtual and the concrete materials alike engaging and relevant. For teacher candidates in a Mathematics Teaching course, nearly any structured hands-on activity has novelty value, above all when it breaks with the lecture-based format so typical of university instruction (Şahin, 2015); the near-ceiling scores probably reflect just that. So even if the virtual materials did carry extra motivational qualities, the immediate feedback and the sense of control emphasized by Ryan and Deci (2000) among them, such advantages had no room left to surface as significant differences once the concrete condition had filled the upper range of the scale. Skulmowski and Xu (2022) made a similar observation: when both conditions are novel and task-relevant rather than routine, self-reported engagement in digital environments often converges with what is reported in non-digital ones. Future studies that add behavioral engagement indicators, time-on-task, help-seeking frequency, or voluntary exploration of the material, to self-report scales may find it easier to catch motivational differences between material types.

From the perspective of teacher education, the findings of this study carry implications that go beyond the immediate learning outcomes that were measured. Pre-service teachers who experience virtual manipulatives as learners are, at the same time, forming a model of what technology-integrated instruction looks like in practice (Gökkurt Özdemir et al., 2020). The fact that the experimental group reached both higher spatial performance and higher germane cognitive load, which is considered an indicator of deeper schema construction, suggests that instruction based on virtual materials may serve two functions in teacher preparation programs. Such instruction develops the spatial skills that pre-service teachers will need as mathematics educators and, at the same time, provides them with a concrete example of technologyenhanced learning design that they have experienced themselves. When virtual manipulatives are presented only as theoretical knowledge within coursework, this second contribution does not emerge. For this reason, integrating researcher-developed virtual environments into methods courses, instead of limiting technology experience to elective or supplementary modules, can be considered a meaningful answer to the gap that Yıldız and Tüzün (2011) described between knowing about spatial tools and using them productively.

5. RECOMMENDATIONS

This study examined the effects of virtual and concrete instructional materials on the spatial skills, cognitive load levels, and motivation of pre-service primary school teachers, and three main conclusions emerge from the findings. First, the spatial activities based on virtual materials produced significantly greater gains in spatial visualization than the activities based on concrete materials, since the within-group effect was large in the experimental group ($d = 1.06$) while the improvement in the control group remained small and non-significant ($d = 0.12$). This result suggests that dynamic transformation, multi-perspective presentation, and immediate feedback, the central opportunities virtual manipulatives bring, make the learning experience for spatial tasks qualitatively different, not simply a more efficient copy of what concrete materials already provide. Second, the cognitive mechanism behind this advantage looks selective: germane cognitive load, the dimension tied to schema construction and deep learning, rose at a significant level in the virtual condition ($p = .039$, $d = 0.75$), and no corresponding rise appeared in intrinsic or extraneous load. Such a pattern agrees with the principles of Cognitive Load Theory (Sweller et al., 2019); the virtual environment used in the study was, in other words, cognitively efficient as well as effective. That extraneous load showed no difference indicates an interface structured well enough to avoid the distraction and split-attention costs frequently reported for digital learning environments (Skulmowski & Xu, 2022). Third, motivation scores were comparably high for both material types, with no significant difference between the groups; this does not make motivation unimportant for material selection, it rather shows that both conditions were motivationally adequate for pre-service teachers working on novel, structured spatial tasks. In every motivational sub-dimension the direction of the difference favoured the virtual condition; the advantage was statistically modest, yet it remains practically noteworthy and worth examining over longer instructional periods.

Taken as a whole, these conclusions carry one main message for mathematics teacher education: bringing virtual manipulatives into methods courses gives pre-service teachers stronger spatial skill development and, beyond that, firsthand experience of technology-integrated instruction that runs in a cognitively efficient way. A teacher candidate who has personally used well-designed virtual tools during training will be better placed, as a future designer of learning environments, to make principled material choices in his or her own classroom (Gökkurt Özdemir et al., 2020; Yıldız & Tüzün, 2011).

Several limitations of this study should be kept in mind when the findings are interpreted and generalized. The sample came from a single institution and covered only third-year pre-service teachers; the results may therefore not extend to other educational levels, other experience groups, or other institutional settings. The intervention lasted three weeks, long enough to detect differences in performance and cognitive load, but perhaps too short for lasting motivational change or retention effects to show themselves. In addition, the cognitive load and motivation measures were based on self-report and were not supported with behavioral indicators, think-aloud protocols, or observational data, which limits the depth of the inferences that can be made about the process.

Some further limitations should also be mentioned explicitly. The group sizes (n = 19 and n = 17) are relatively small and limit statistical power, especially for the between-group comparison that lies closest to the significance threshold. In addition, the germane load sub-dimension was analyzed without a correction for multiple comparisons across the three cognitive load sub-dimensions. Therefore, this should be kept in mind when this result is interpreted. The participants were assigned within a single intact course cohort rather than being sampled from a wider population, and this feature affects the extent to which the design can be described as fully experimental. Moreover, the intervention depended on a single software environment, and implementation fidelity, for example the equivalence of time-on-task or the consistency of the facilitator, was not verified independently. Finally, no delayed posttest was administered, and for this reason it is not known whether the spatial visualization gains observed immediately after the intervention are durable.

Based on the findings and the limitations of this study, the following directions can be recommended for future research:

- Studies to be conducted with larger and more diverse samples, which would include different grade levels, different disciplines, and different profiles of prior technology experience, are needed in order to establish how far the advantage of virtual manipulatives in spatial learning can be generalized.
- Longitudinal designs with delayed retention tests would show whether the germane load advantage of virtual materials settles into durable spatial schemas or loses strength as time passes.
- Supporting self-report cognitive load measures with process-based indicators, eye tracking, response latency, or verbal protocols for example, would also help, since the moment-to-moment cognitive dynamics of working with virtual and concrete materials could then be followed more closely.
- Looking at individual differences as moderators, prior spatial skill above all, but also familiarity with technology and working memory capacity, would clarify which learners gain the most from virtual materials and under which conditions.
- Mixed designs, where virtual and concrete materials come one after the other or together, could show whether the representational strengths of the two material types complement or substitute for each other, which would give instructional design more detailed guidance.

6. ABOUT THE AUTHORS

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