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Exploring middle school students' perceptions of scientific models and modelling: recall, preference, and impact

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Abstract. Scientific models help students visualise concepts and processes that would otherwise remain abstract. This qualitative study examined how middle school students experience and perceive various modelling practices in science education. We conducted semi-structured interviews with 15 students across grades 5–7 to understand their preferences and the perceived impact of various modelling techniques. Students most frequently recalled and preferred physical and experimental modelling, viewing these hands-on approaches as most valuable for their learning. We observed moderate differences across grade levels and genders, pointing to the need for varied instructional strategies. Based on these findings, we recommend that physical and experimental modelling serve as core teaching strategies, supplemented by game-based, creative, and biological modelling to address diverse learning preferences.

Keywords: science education, scientific modelling, student perception, middle school, physical modelling

1. Introduction

Science education aims to help students understand the natural world and develop scientific thinking skills [4, 9]. Models and modelling make abstract concepts tangible, improving both student comprehension and instructional clarity [4, 9].

Through modelling, students grapple with scientific concepts and break down complex systems [3, 26]. The process strengthens scientific reasoning as students construct and test hypotheses, increasing their engagement with science [45].

A model is a simplified representation of a phenomenon, event, or system. Models differ from what they represent; they cannot capture every detail [52]. If a model perfectly matched its target, it would be a replica rather than a model [36]. Modelling, in contrast, is the process of building and refining models [9]. This process involves representing objects, phenomena, processes, and systems [10]. Because modelling involves development, assessment, and revision, the model itself is the product of this process [47].

Consider atomic structure: we cannot see atoms directly, but augmented reality lets students visualise and manipulate 3D atomic models [55]. Similarly, activities such as calibrating an NTC thermistor with simulations or designing a micrometre in CAD software help students develop practical skills while learning science [38]. Such experiences teach students to view models as tools for investigation rather than fixed information sources.

When students engage in modelling, they employ scientific process skills and develop an understanding of how scientific knowledge is constructed [21]. Establishing a

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conceptual foundation for these practices helps teachers organise and assess their educational impacts [52].

Effective evaluation of models in science education requires a multimodal approach that considers both the final model and the modelling process [13, 20]. Modelling instruction should support conceptual, epistemic, and social dimensions of learning [13, 20]. Students need guidance to understand the nature and purpose of modelling [22], enabling them to view models as dynamic inquiry tools rather than static representations [22].

Educational environments should also be fair and inclusive. Teachers must consider who creates models and whose perspectives are incorporated [20]. Students need opportunities to design and refine their own models [22], and multimodal approaches should recognise that visual, verbal, and physical expressions all contribute to the modelling process [20].

2. Literature review

Research on models and modelling in science education focuses on two main areas: evaluating the effectiveness of modelling practices and understanding the conceptual foundations of models themselves [9, 19, 21, 32, 54].

Studies typically employ comparative designs, with experimental groups engaging in modelling activities and control groups receiving traditional instruction [19, 32, 54]. Research consistently shows positive effects of modelling on learning outcomes in three areas:

(1) Conceptual understanding and achievement [9, 19, 21, 32, 54]
(2) Skill development, including modelling skills, scientific process skills, and attitudes toward science [9, 21, 54]
(3) Cognitive representations, including correction of misconceptions and use of multiple representations [9, 19, 32, 53]

Research also examines mental models – how students internally represent scientific ideas [6, 13, 34, 35]. Understanding these mental structures helps shape modelling activities [53].

Recent work integrates advanced technologies such as computer simulation and augmented reality [38, 39, 55]. These tools support practical STEM skills [39], including remote laboratory work, such as thermistor calibration or CAD modelling [38]. AR proves particularly useful for teaching abstract subjects that resist direct observation [55], allowing students to visualise concepts like atomic structure in 3D. However, maximising these technologies' benefits requires improved software interfaces and appropriate pedagogical strategies.

Beyond effectiveness, research examines the perspectives that students and teachers hold about models and their purposes [16, 19, 21]. While modelling is recognised internationally as an essential educational tool, gaps between theory and practice persist [18, 35]. Progress requires proper teacher training [9, 35] and equipping students with modelling skills. Research on students' own perspectives remains critical for identifying learning gaps [6, 9, 16].

2.1. The role of models and modelling in science education

Models depict complex scientific phenomena in a way that makes them accessible. They help students visualise abstract ideas, understand system connections, and predict outcomes. Creating and refining models reflects the scientific method, offering insight into how scientific knowledge develops.

Model-based instruction offers several benefits:

- *Learning and retention:* Models help students grasp and retain scientific concepts, particularly by making abstract ideas concrete [1, 4, 14, 26, 45].
- *Student achievement:* Students in modelling-based environments show better understanding and higher achievement than those in traditional settings [1, 4].
- *Active learning:* Models boost motivation and engagement. Students who build, assess, and improve their own models develop cognitive structures and critical thinking [14, 52].
- *Scientific process skills:* Creating and evaluating models develops scientific reasoning and engineering design abilities [1, 27, 52].
- *Mental model development:* Through modelling, students build and refine their mental models, promoting conceptual advancement [1, 14, 52].
- *Understanding scientific knowledge:* By exploring how models are developed and assessed, students enhance their understanding of science [1, 3].

2.2. Classification of models in academic literature

Researchers classify models in various ways. Harrison and Treagust [28] suggest organising models by abstraction level and conceptual complexity, including scale, conceptual/process, theoretical, and analogical models. Another view emphasises that models primarily make phenomena understandable and examinable [16].

Studies have examined various modelling types, including pedagogical analogue models, scale models, mental and conceptual models [33], mathematical and theoretical models, physical models [42], explanatory and descriptive models [46], and visual modelling [54].

For this study, we defined modelling types based on specific applications:

- *Physical modelling* – tangible representations of physical systems
- *Creative modelling* – student-designed models using creativity
- *Biological modelling* – modelling of living systems and processes
- *Experimental modelling* – data gathering through observation and experimentation
- *Visual modelling* – visual tools representing concepts
- *Computer simulation* – digital replication of real-world systems
- *Drama-based modelling* – teaching through role-playing and enactment
- *Design-based modelling* – learning through hands-on design creation
- *Mathematical modelling* – equations and algorithms representing systems
- *Representational modelling* – symbolic or scaled representations
- *Game-based modelling* – learning through games
- *Conceptual modelling* – mental structures organizing abstract relationships
- *Educational modelling* – instructional models for learning
- *Abstract modelling* – making abstract concepts understandable
- *Quantitative modelling* – numerical data modelling systems
- *Sensory modelling* – perceiving processes through senses

2.3. Research questions

This study explores middle school students' perceptions of models and modelling in science education:

RQ1: Which modelling approaches do students find most memorable from their science education?
RQ2: Which approaches do students prefer, and what factors shape these preferences?
RQ3: Which models do students feel confident constructing independently?
RQ4: Which modelling techniques have the strongest emotional or cognitive impact?
RQ5: Which approaches best support students' conceptual understanding?
RQ6: Which approaches do students perceive as less important for their learning?

3. Method

3.1. Research design

We used a phenomenological design to explore students' views on models and modelling [2, 15]. Phenomenological research reveals how individuals experience a phenomenon and what meanings they assign to it. This study investigated students' perceptions, preferences, and experiences with various modelling approaches.

3.2. Participants

We conducted the study at a public middle school with a medium socioeconomic profile in a small province. Using maximum variation sampling [37, 40], we selected 18 students: three female and three male students from each grade level (5th, 6th, and 7th), ages 10–13 (figure 1).

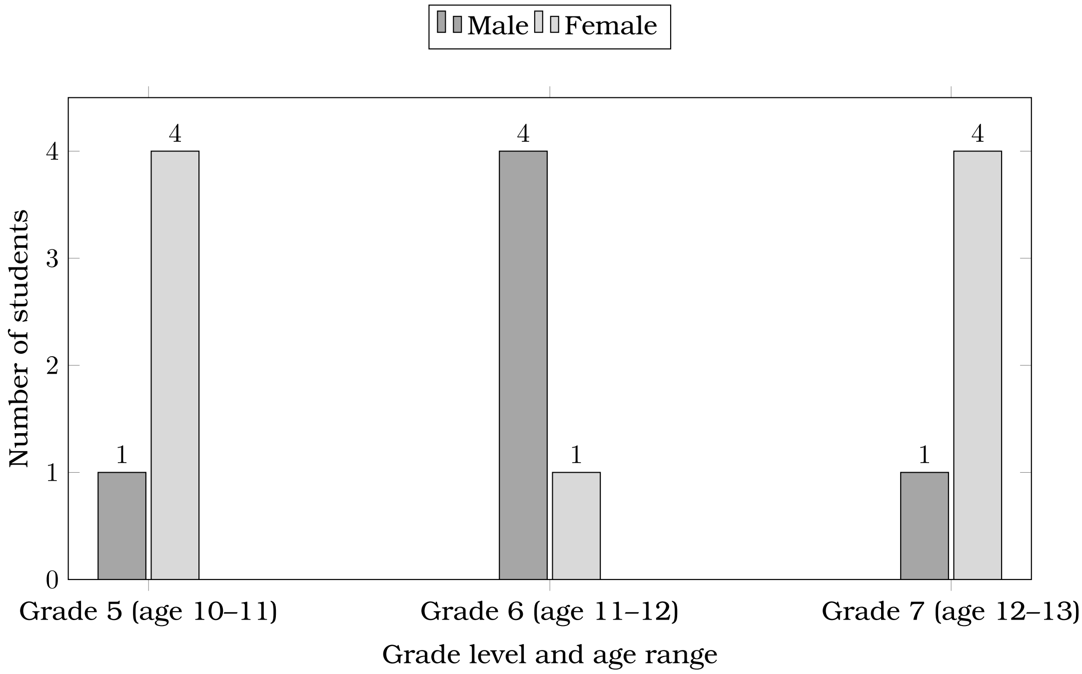

Figure 1: Student distribution by grade level and gender

The modelling activities in this study were integrated into the science curriculum throughout the academic year. Appendix A provides details on the specific units, modelling types, and implementation across grade levels.

3.3. Data collection and analysis

We conducted semi-structured interviews, which were audio-recorded and lasted approximately three minutes each. To maintain a relaxed environment, we scheduled interviews during class breaks. All recordings were transcribed verbatim and verified for accuracy.

Of the 18 students invited, we excluded three interviews because the students provided extremely short answers, skipped questions, or gave unrelated responses. The final sample consisted of 15 students (nine females and six males), with five students per grade level. Data saturation occurred at the fifteenth interview, with no new themes emerging thereafter.

We analysed transcripts using conventional content analysis with NVivo 12 (QSR International). Two researchers independently coded the transcripts, generating initial codes from meaningful passages in an inductive approach. We grouped similar codes into six themes addressing our research questions:

1. Model types remembered
2. Preferred models
3. Doable models
4. Impressive models
5. Essential modelling types
6. Non-essential modelling types

Inter-coder reliability was assessed using per cent agreement and Cohen's κ. Agreement ranged from 0.72 to 0.98 across themes – levels considered substantial to almost perfect [30]. Figure 2 shows the agreement distribution.

Code	File	File Folder	File Size	Kappa	Agreement (%)	A and B (%)	Not A and Not B (%)	Disagreement (%)
Model Types	5-e-Y	Files	2558 chars	0,9504	99,84	1,52	98,32	0,16
Model Types	5-k-E	Files	2748 chars	0,9688	99,82	2,91	96,91	0,18
Model Types	5-k-H	Files	2809 chars	0,9547	99,64	3,92	95,73	0,36
Model Types	5-k-I	Files	2534 chars	0,8769	99,21	2,92	96,29	0,79
Model Types	5-k-p	Files	2580 chars	0,9884	99,92	3,41	96,51	0,08
Model Types	6-e-A	Files	2539 chars	0,7269	98,19	2,52	95,67	1,81
Model Types	6-e-AS	Files	1367 chars	0,9807	99,78	5,93	93,86	0,22
Model Types	6-e-O	Files	2439 chars	0,9636	99,63	5,17	94,46	0,37
Model Types	6-e-y	Files	1528 chars	0,8836	98,76	5,04	93,72	1,24
Model Types	6-k-B	Files	2612 chars	0,9744	99,81	3,79	96,02	0,19
Model Types	7-e-E	Files	2551 chars	0,9432	99,76	2	97,77	0,24

Figure 2: Coding reliability analysis performed using NVivo.

3.4. Ethical approval

We obtained approval from the Erzincan Binali Yildirim University Ethics Committee (Approval No. 14/07, Date: 29 December 2023) and official permission from the Provincial National Education Directorate.

For consent, we distributed written informed consent forms to parents explaining the research purpose, methods, and participant rights. After receiving parental consent, we obtained verbal assent from students after explaining the study in age-appropriate terms. Participation was voluntary, and students could withdraw at any time. We anonymised all data and maintained confidentiality throughout.

4. Results

We organised the findings into six categories, reflecting themes from the data analysis: recalled model types, preferred models, feasible models, impactful models, essential modelling types, and non-essential modelling types.

4.1. Recalled model types

Students spontaneously recalled 10 of the 16 model types introduced during the term (figure 3). Physical modelling (57 references) and experimental modelling (41 references) dominated student recollections, together comprising the bulk of 164 total references. Game-based modelling (24 references) and creative modelling (12 references) appeared moderately often; other types were mentioned less frequently.

These recall frequencies reflect memorability rather than educational effectiveness. The prominence of physical and experimental modelling likely stems from their hands-on and interactive nature. Female students contributed slightly more responses, but both genders showed comparable patterns. Grade-level differences in theme formation are shown in figure 4.

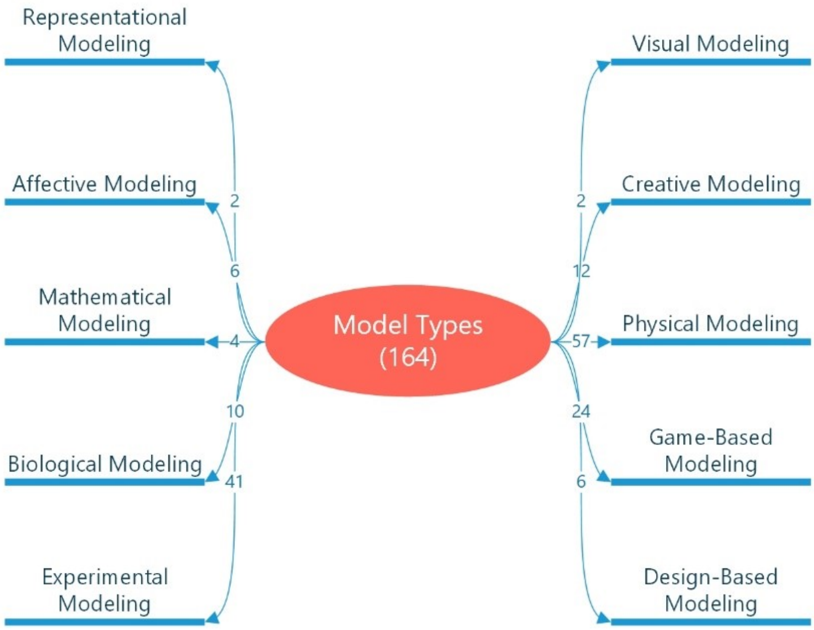

Figure 3: Model types recalled by students.

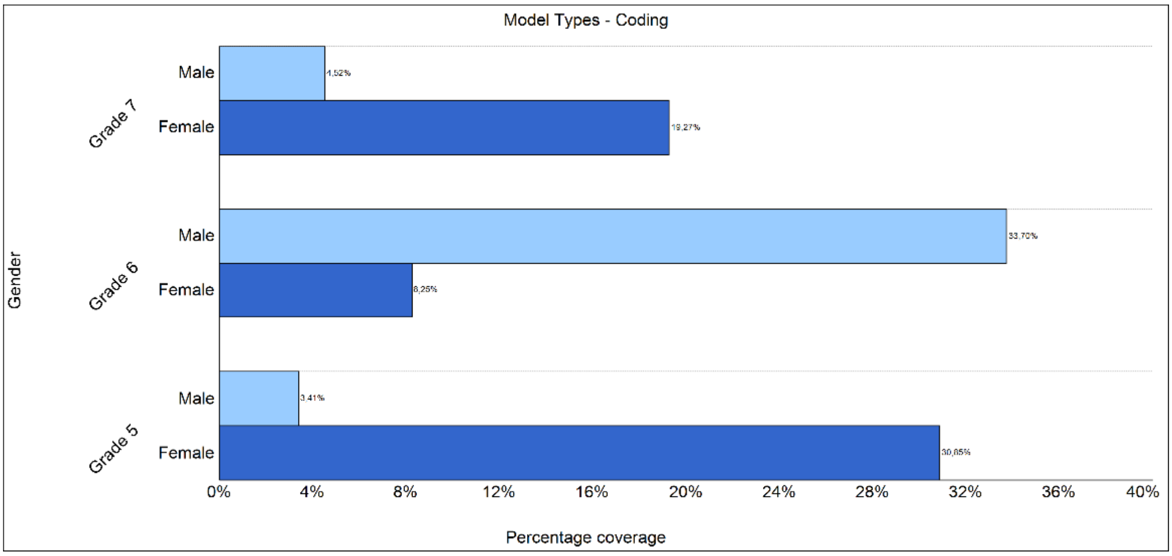

Figure 4: Participation by gender and grade level (recalled model types).

4.2. Preferred models

Students identified seven preferred model types from 68 total references (figure 5). Physical modelling led with 22 mentions, followed by experimental (9) and biological modelling (6).

When explaining their preferences, students cited motivational engagement and visual learning (4 references each) most often. Students also mentioned game-based learning, experiential learning, collaborative learning, making abstract concepts concrete, and memory retention. Grade-level patterns varied (figure 6): female students' views dominated in grades 5 and 7, while no female opinions appeared in grade 6. Overall, both genders contributed equally.

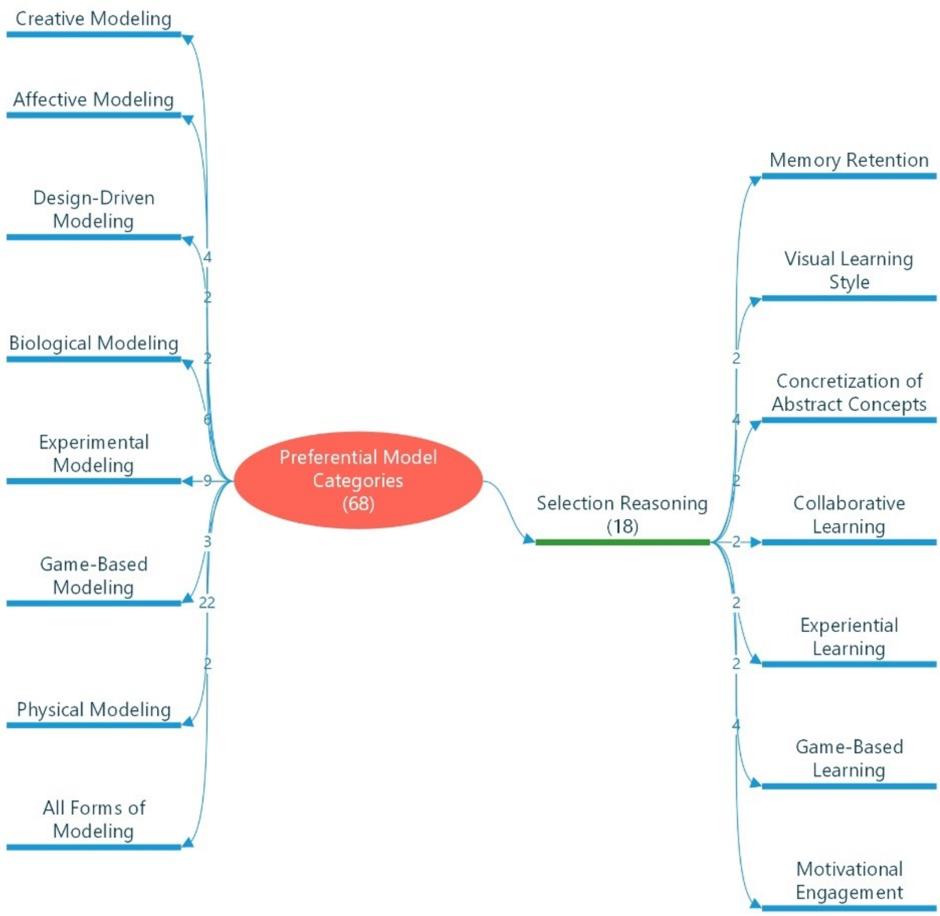

Figure 5: Preferred model categories.

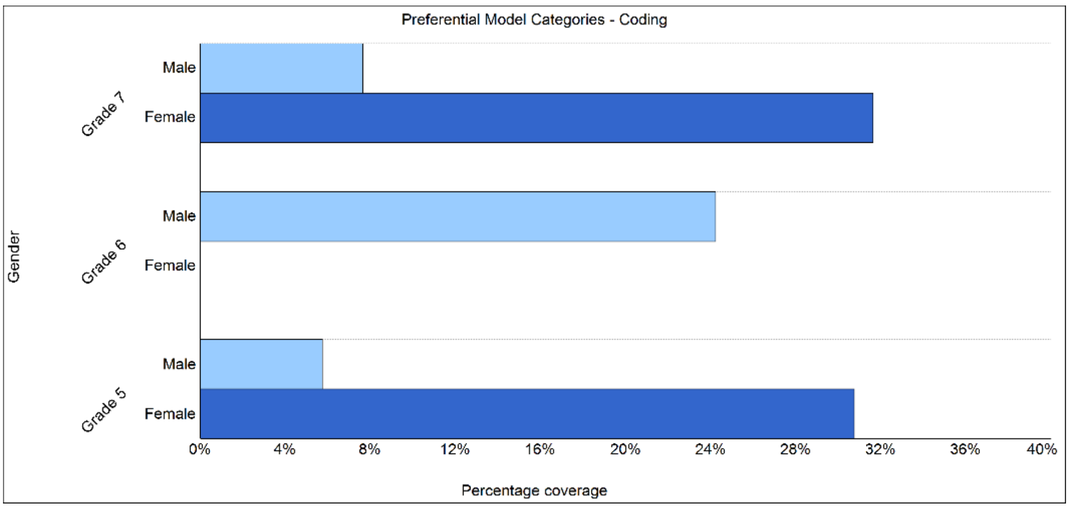

Figure 6: Participation by gender and grade level (preferred models).

4.3. Models students felt capable of creating

From 62 references, students identified five feasible model types (figure 7). Experimental modelling (20) and physical modelling (22) were seen as most achievable. Creative, design-driven, and drama-based modelling (2 each) was considered less feasible. Two students stated they could not create any model.

Students chose models based on practicality and learning retention (4 references each), with previous success and material availability as secondary factors (2 each). Female students' views were more prominent in grades 5 and 7; male views dominated in grade 6 (figure 8).

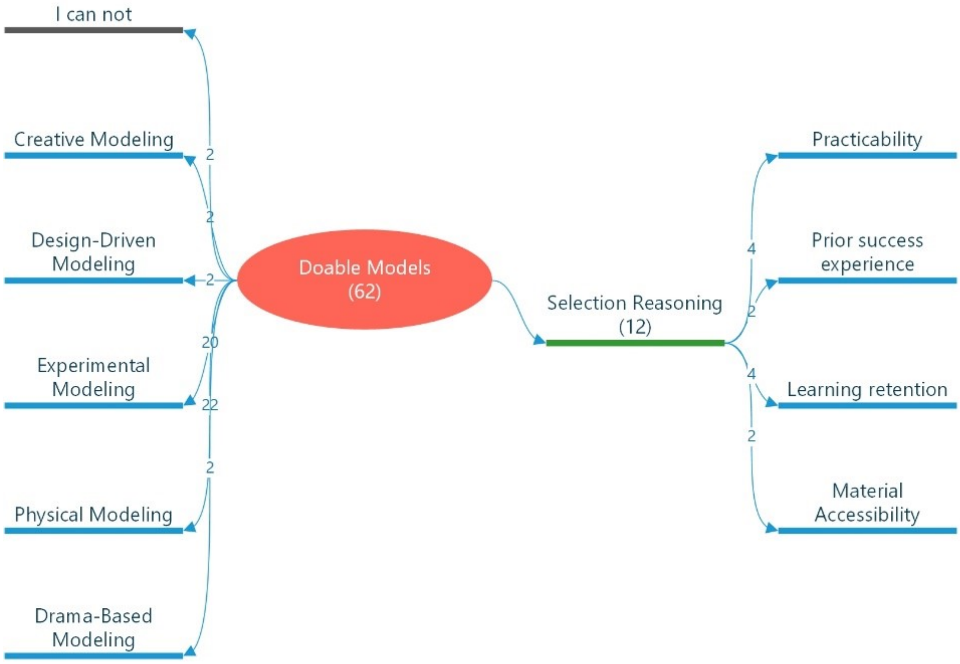

Figure 7: Models students felt capable of creating.

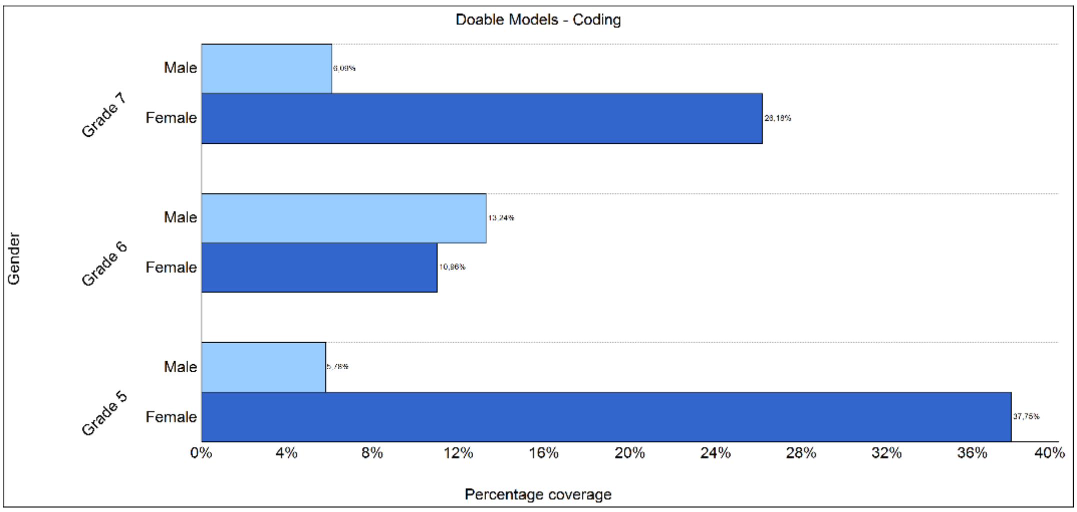

Figure 8: Participation by gender and grade level (feasible models).

4.4. Models with greatest impact

Seven model types were identified as impactful from 86 references (figure 9). Experimental (20) and physical modelling (18) had the most significant impact. Biological (6) and drama-based modelling (4) showed moderate impact; design-driven, game-based, and sensory modelling (2 each) had lower impact.

Visual appeal (10 references) was the primary factor making models impactful. Creativity and surprise (each with four factors) were secondary factors. Other characteristics included impressiveness, topic specificity, research involvement, competitive

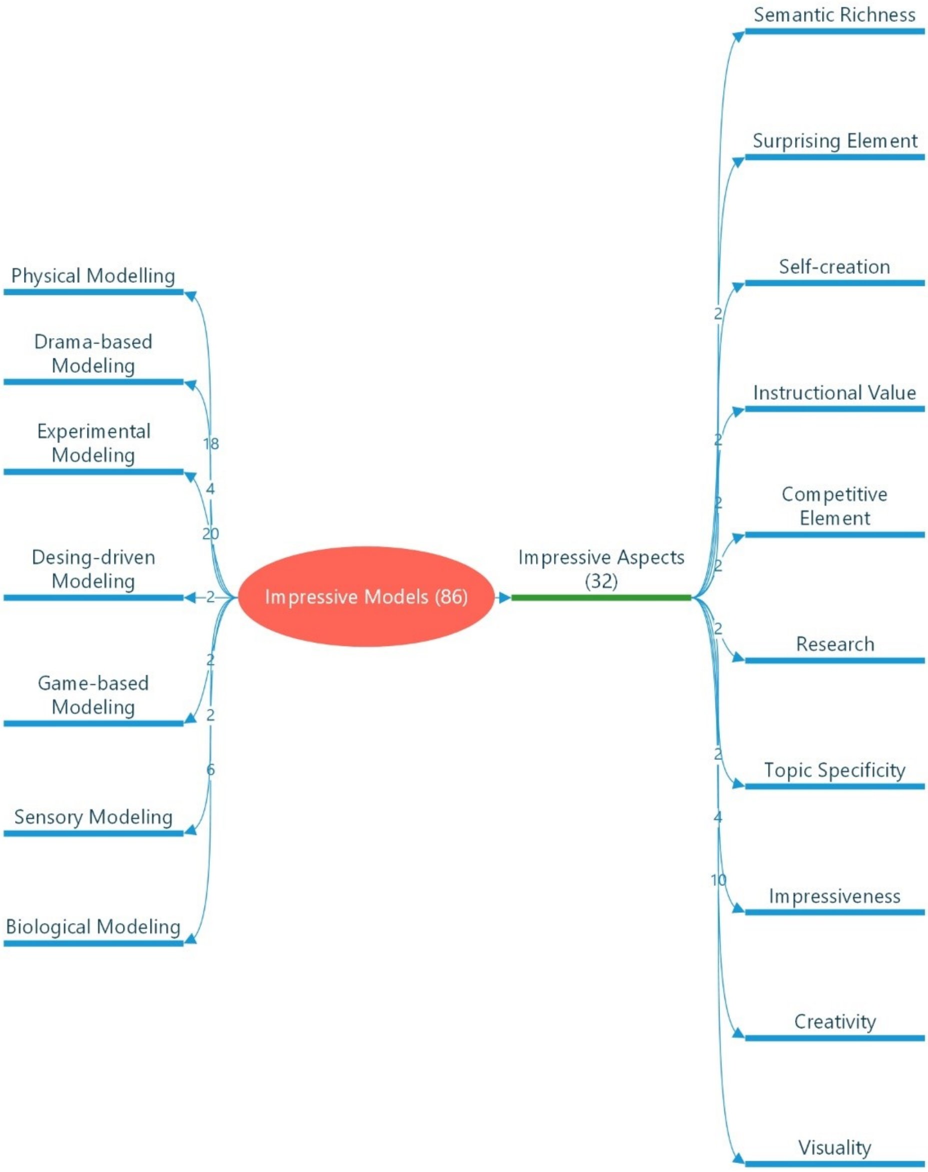

Figure 9: Models with greatest impact on students.

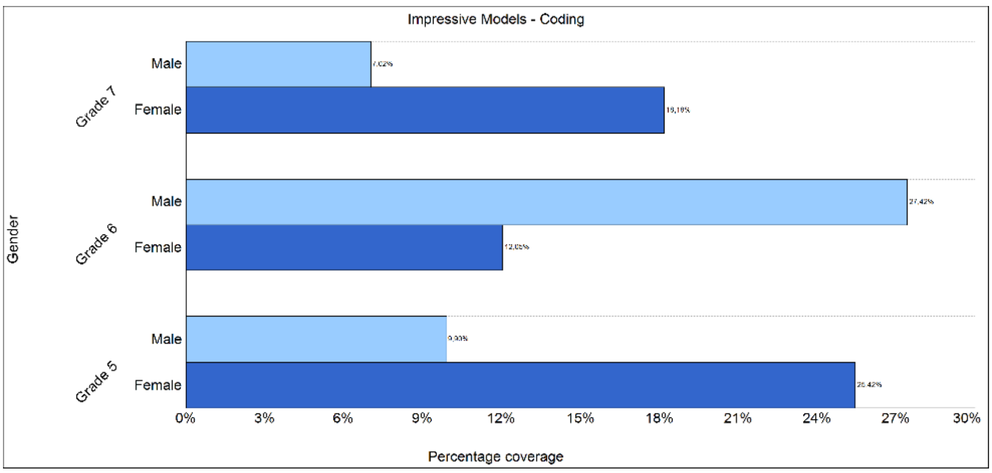

Figure 10: Participation by gender and grade level (impactful models).

elements, instructional value, self-creation, and semantic richness (each with two ratings). Both genders contributed equally overall (figure 10).

4.5. Models considered essential for understanding

From 56 references, students identified seven essential model types (figure 11). Physical (18) and experimental modelling (14) were most essential. Sensory modelling (6) was found to be of moderate importance; biological, creative, game-based, and design-driven modelling (4, 4, 2, 2) were deemed less essential.

Two opposing views emerged: some students felt no model was essential (4 references), while others considered all models necessary (2). Female views were more prominent in grade 5, male views in grade 6, with equal distribution in grade 7 (figure 12).

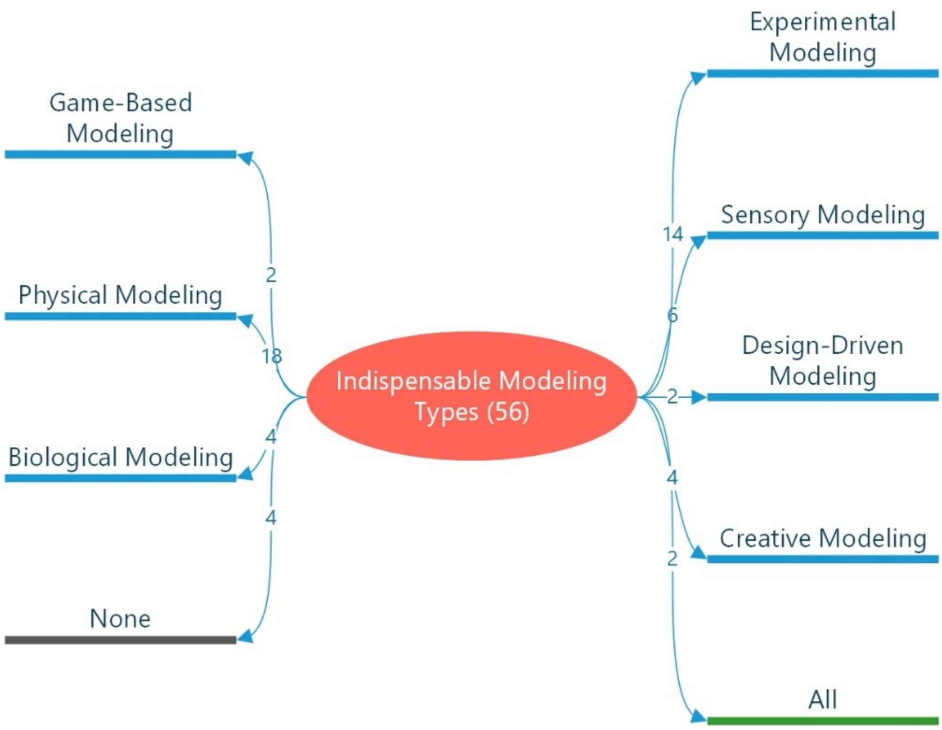

Figure 11: Model types considered essential for understanding.

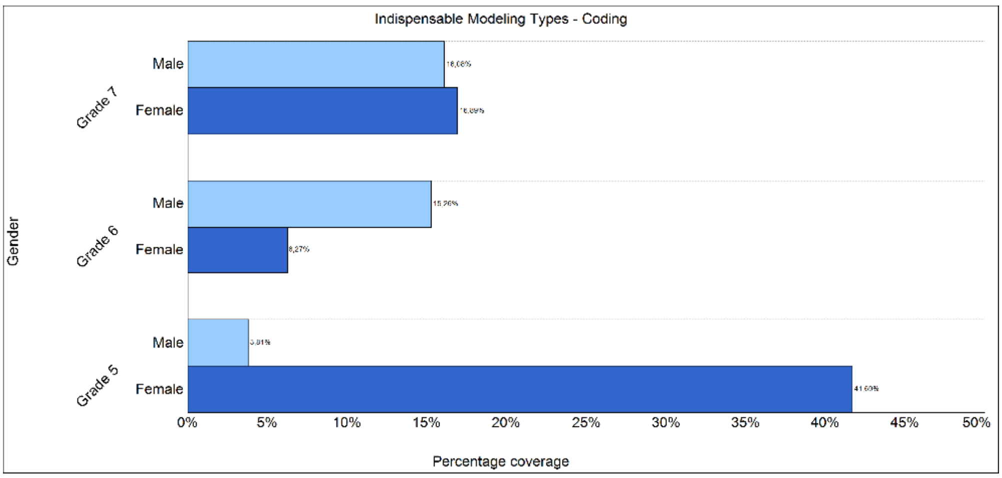

Figure 12: Participation by gender and grade level (essential models).

4.6. Models considered non-essential

Four model types were identified as non-essential from 36 references (figure 13). Physical (12) and experimental modelling (6) were the most frequently cited approaches in this category, followed by game-based and creative modelling (2 each).

However, "None" received 12 references, indicating that many students viewed no model type as unnecessary. A few students (2) considered all models unnecessary. Gender contributions were roughly equal across grades (figure 14).

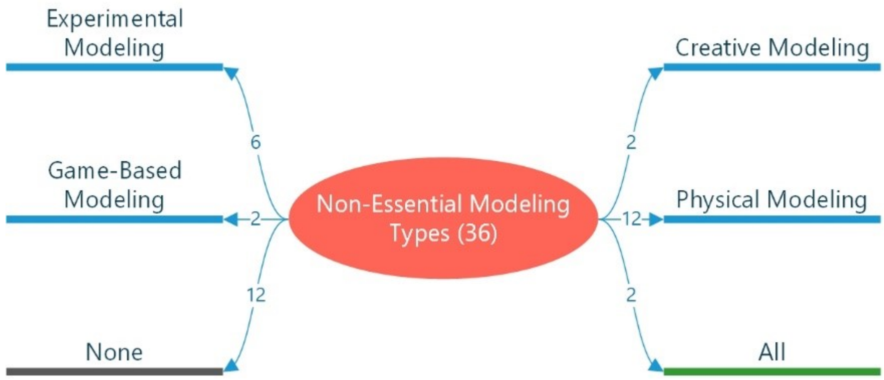

Figure 13: Model types considered non-essential.

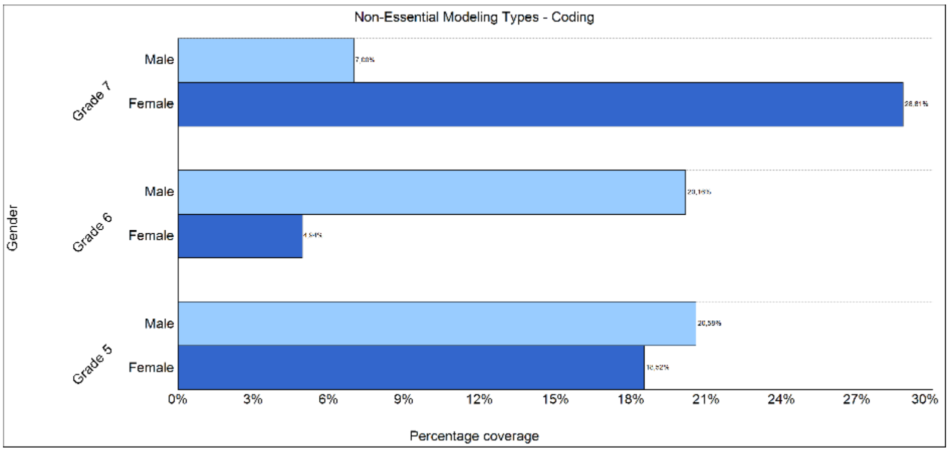

Figure 14: Participation by gender and grade level (non-essential models).

5. Discussion

5.1. Model recall patterns

Students recalled 10 of 16 model types, indicating that multiple approaches registered in their awareness. Physical and experimental modelling dominated recollections, likely due to their hands-on nature.

Physical models are three-dimensional material representations that connect with sensory experience [25]. Students often associate models with familiar objects, such as toy cars or miniature houses [50], making physical models easier to recall. Experimental modelling involves investigating phenomena, making predictions, and testing them [5, 25, 44]. Active participation in creating and refining models enhances retention [12].

Game-based and creative modelling showed moderate recall, suggesting potential for engaging students. Games make learning more motivating and less stressful [7].

Creative modelling enables students to become active knowledge creators, fostering a deeper understanding [29].

The roughly equal involvement of both genders suggests that modelling activities appeal across genders, supporting their use in promoting gender equity in science education.

5.2. Model preferences

The preference for physical modelling (22 mentions) confirms that students value hands-on, interactive learning. The correspondence between recalled and preferred models reinforces this pattern. Biological models ranked third, perhaps because they simplify living systems and connect to students' daily lives [11, 43, 51].

Students valued motivational engagement and visual learning most when explaining preferences. Interest and motivation are central to learning [17, 48]. Modelling activities can stimulate intrinsic motivation by making content personally meaningful [17]. Visual modelling may particularly engage students with visual learning preferences [48, 51].

Students' openness to game-based, experiential, and collaborative learning shows receptiveness to varied approaches. Their emphasis on making abstract concepts tangible highlights an appreciation for practical methods of understanding complex ideas.

5.3. Feasibility perceptions

Students felt most capable of creating experimental and physical models, consistent with their preferences. Limited confidence in creative, design, and drama-based modelling suggests that these areas may require additional support.

That some students felt unable to create any model indicates not all students have developed modelling skills [21, 54]. Modelling involves multiple stages: stimulus, observation, creation, evaluation, and revision [31]. Students may struggle at any stage. Schwarz et al. [44] noted that students often view model creation as representing existing information rather than generating new knowledge. Without opportunities to evaluate and revise models, students may see model creation as fixed, leading to hesitance.

5.4. Impact factors

Experimental and physical modelling had the most substantial impact, consistent with other findings. Students cited visual appeal as the primary factor, followed by creativity and surprise.

Concrete, easily visualised models are more comprehensible and memorable [17, 24]. Experimental modelling captures interest through observable results. Both approaches allow students to use their creativity by creating, testing, and revising their own models [23]. This active role makes modelling more engaging.

These findings suggest that modelling types offering concrete experiences have a greater cognitive and affective impact, emphasising the importance of incorporating experimental and physical modelling into curricula.

5.5. Essential versus non-essential models

Physical and experimental modelling were deemed most essential, reflecting a preference for tangible, experience-based learning. Other modelling types were viewed as less critical, possibly because they are less common in current instruction or students are less aware of their benefits.

The differing views – some seeing no model as crucial, while others finding all essential – reflect diverse learning preferences. Models vary in form and function

[25, 49] and can be adapted to incorporate new data [41]. Educational design should offer various modelling methods, allowing students to choose the one that suits them.

The apparent contradiction in findings about non-essential models is resolved when considering the high rate of “None” responses: most students found all models to be important. This suggests that, from the students’ perspectives, the modelling approaches used during the term were valuable.

5.6. Gender and grade patterns

Variations across grade levels and genders suggest that age and gender may influence how students value different types of modelling. The prominence of female perspectives in some grades may reflect different inclinations toward dialogue and sharing ideas [8], or the topics may have resonated more with female students. These patterns require further research before broader generalisations.

Teachers should diversify their methods and promote active participation from all students, taking into account both gender and age differences.

6. Recommendations

6.1. For practice

Our findings show students strongly prefer physical and experimental modelling. Hands-on modelling should be central to science instruction, rather than an optional enrichment. Curricula should incorporate repeated cycles of building, testing, and revising models, enabling students to become active participants in constructing scientific knowledge.

Students also responded positively to game-based, creative, and biological modelling, indicating that varied approaches cater to different learning styles. Teachers can create inclusive classrooms by incorporating diverse formats – physical models, digital simulations, and creative representations.

These changes require shifts in professional development. Rather than lecture-based workshops, professional development should provide hands-on modelling experiences where teachers act as designers, testers, and evaluators of their own work. This prepares teachers to recognise student struggles, offer support, and emphasise the process over finding “correct” answers.

Students’ difficulties with certain modelling stages highlight the need for explicit support: modelling rubrics, reflection prompts, and targeted feedback. By normalising revision and promoting a growth mindset, teachers help students view challenges as learning opportunities.

6.2. For theory

Our findings reveal six modelling categories that students recognise: physical-experimental, game-based, creative, biological, essential, and non-essential. This taxonomy connects theories of scientific practice to students’ actual learning experiences.

The consistency of students’ memory, preference, and perceived value for physical-experimental modelling supports the embodied cognition theory – physical engagement strengthens conceptual understanding. When students manipulate materials and conduct experiments, hands-on experience enhances learning and retention.

These findings contribute a student-centred perspective to modelling literature. While previous research focused on what modelling should look like or how teachers implement it, this study reveals how students understand and value different approaches.

6.3. For future research

Several questions remain:

- *Longitudinal studies:* Following students across middle school years would reveal how modelling skills, beliefs, and preferences develop. Such research could determine whether early hands-on experiences produce lasting benefits.
- *Teacher perspectives:* Research on teachers' experiences implementing modelling instruction – their challenges, needs, and strategies – would help identify barriers and improve professional development.
- *Equity and context:* Studies examining how grade level, gender, socioeconomic background, and school resources affect preferences could inform more equitable approaches.
- *Comparing approaches:* Experimental studies comparing different modelling combinations would clarify whether varied formats enhance learning beyond single-approach instruction.

References

[1] Aktan, M.B., Kaynak, S., Abdüsselam, Z. and Ardoğan, E., 2019. Güncel fen öğretim programları ve ders kitaplarında model ve modelleme kavramlarının analizi [Analysis of model and modeling concepts in current science education curricula and textbooks]. *Cumhuriyet International Journal of Education*, 8(1), pp.44–69. Available from: https://doi.org/10.30703/cije.450242.

[2] Alase, A., 2017. The Interpretative Phenomenological Analysis (IPA): A Guide to a Good Qualitative Research Approach. *International Journal of Education and Literacy Studies*, 5(2), pp.9–19. Available from: https://doi.org/10.7575/aiac.ijels.v.5n.2p.9.

[3] Altan, E.B., Okurlar, H., Öz, G.K. and Taner, M.S., 2024. Lise ve Lisans Düzeyinde Uygulanabilir Model Geliştirme İçerikli Bir Etkinlik Önerisi: Güneş-Dünya-Ay Hareketleri [An activity proposal including model development applicable at high school and undergraduate level: Sun–Earth–Moon movements]. *Journal of Research in Informal Environments*, 9(2), pp.174–198. Available from: https://dergipark.org.tr/en/download/article-file/3991715.

[4] Altay, E., Didiş Körhasan, N. and Demirdöğen, B., 2021. Teachers' Pedagogical Content Knowledge for Models and Modeling in Science Teaching. *Karaelmas Journal of Educational Sciences*, 9, pp.64–83. Available from: https://dergipark.org.tr/tr/download/article-file/1600985.

[5] Areepattamannil, S., 2012. Effects of Inquiry-Based Science Instruction on Science Achievement and Interest in Science: Evidence from Qatar. *The Journal of Educational Research*, 105(2), pp.134–146. Available from: https://doi.org/10.1080/00220671.2010.533717.

[6] Bati, K. and Kaptan, F., 2015. The Effect of Modeling Based Science Education on Critical Thinking. *Educational Policy Analysis and Strategic Research*, 10(1), pp.39–58. Available from: https://dergipark.org.tr/en/download/article-file/161896.

[7] Bayırtepe, E. and Tüzün, H., 2007. Oyun-tabanlı öğrenme ortamlarının öğrencilerin bilgisayar dersindeki başarıları ve öz-yeterlik algıları üzerine etkileri [The effects of game-based learning environments on students' computer course success and self-efficacy perceptions]. *Hacettepe Universitesi Egitim Fakultesi Dergisi*, 33, pp.41–54. Available from: https://dergipark.org.tr/en/download/article-file/87632.

[8] Belenky, M.F., Clinchy, B.M., Goldberger, N.R. and Tarule, J.M., 1986. *Women's*

Ways of Knowing: The Development of Self, Voice, and Mind. New York: Basic Books.

[9] Benzer, A.I. and Ünal, S., 2021. Models and modelling in science education in Turkey: A literature review. *Journal of Baltic Science Education*, 20(3), pp.344–359. Available from: https://doi.org/10.33225/jbse/21.20.344.

[10] Boulter, C.J. and Buckley, B.C., 2000. Constructing a Typology of Models for Science Education. In: J.K. Gilbert and C.J. Boulter, eds. *Developing Models in Science Education*. Dordrecht: Springer Netherlands, pp.41–57. Available from: https://doi.org/10.1007/978-94-010-0876-1_3.

[11] Bryce, C.M., Baliga, V.B., De Nesnera, K.L., Fiack, D., Goetz, K., Tarjan, L.M., Wade, C.E., Yovovich, V., Baumgart, S., Bard, D.G., Ash, D., Parker, I.M. and Gilbert, G.S., 2016. Exploring Models in the Biology Classroom. *The American Biology Teacher*, 78(1), pp.35–42. Available from: https://doi.org/10.1525/abt.2016.78.1.35.

[12] Burch, G.F., Giambatista, R., Batchelor, J.H., Burch, J.J., Hoover, J.D. and Heller, N.A., 2019. A Meta-Analysis of the Relationship Between Experiential Learning and Learning Outcomes. *Decision Sciences Journal of Innovative Education*, 17(3), pp.239–273. Available from: https://doi.org/10.1111/dsji.12188.

[13] Carroll, G. and Park, S., 2024. Towards expansive model-based teaching: A systematic synthesis of modelling pedagogies in science education literature. *Studies in Science Education*, pp.1–39. Available from: https://doi.org/10.1080/03057267.2024.2417157.

[14] Çoban, G.Ü., 2021. Fen Öğretiminde Model ve Modellemenin Önemi [The importance of model and modeling in science education]. In: H. Şevki Ayvacı, ed. *Fen Öğretiminde Model ve Modelleme*. Pegem Akademi, chap. 1, pp.1–42. Available from: https://doi.org/10.14527/9786257582780.

[15] Creswell, J.W. and Poth, C.N., 2007. *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. 2nd ed. Sage Publications. Available from: https://revistapsicologia.org/public/formato/cuali2.pdf.

[16] Danusso, L., Testa, I. and Vicentini, M., 2010. Improving Prospective Teachers' Knowledge about Scientific Models and Modelling: Design and evaluation of a teacher education intervention. *International Journal of Science Education*, 32(7), pp.871–905. Available from: https://doi.org/10.1080/09500690902833221.

[17] Dierking, L.D. and Falk, J.H., 2003. Optimizing out-of-school time: The role of free-choice learning. *New Directions for Youth Development*, 2003(97), pp.75–88. Available from: https://doi.org/10.1002/yd.36.

[18] El Hnot, H., Cherai, B. and Jaouani, M., 2024. Modelling Activities in Qualifying Training for Future Primary School Teachers: An Attractive Way to Train Competent and Innovative Teachers. *Journal of Curriculum and Teaching*, 13(4), pp.15–33. Available from: https://doi.org/10.5430/jct.v13n4p15.

[19] Engelschalt, P., Bielik, T., Krell, M., Krüger, D. and zu Belzen, A.U., 2024. Investigating pre-service science teachers' metaknowledge about the modelling process and its relation to metaknowledge about models. *International Journal of Science Education*, 46(7), pp.691–714. Available from: https://doi.org/10.1080/09500693.2023.2253368.

[20] Fackler, A.K., 2025. "I Thought That They Were Very Cut and Dry": Preservice Elementary Science Teachers Learning About and Learning with Models and Modeling. *Journal of Science Teacher Education*, 36(2), pp.180–202. Available from: https://doi.org/10.1080/1046560X.2024.2380549.

[21] Faikhamta, C., Khan, S., Prasoplarb, T., Praisri, A. and Suknarusaithagul, N., 2024. Pre-service Teachers' Conceptual Understandings of Models and Modelling in a STEM Methods Course. *Research in Science Education*, 54(6), pp.1137–1153.

Available from: https://doi.org/10.1007/s11165-024-10184-3.
[22] Fuhrmann, T., Schneider, B. and Blikstein, P., 2018. Should students design or interact with models? Using the Bifocal Modelling Framework to investigate model construction in high school science. *International Journal of Science Education*, 40(8), pp.867–893. Available from: https://doi.org/10.1080/09500693.2018.1453175.
[23] Gilbert, J.K., 2004. Models and Modelling: Routes to More Authentic Science Education. *International Journal of Science and Mathematics Education*, 2(2), pp.115–130. Available from: https://doi.org/10.1007/s10763-004-3186-4.
[24] Gilbert, J.K., 2008. Visualization: An Emergent Field of Practice and Enquiry in Science Education. In: J.K. Gilbert, M. Reiner and M. Nakhleh, eds. *Visualization: Theory and Practice in Science Education*. Dordrecht: Springer Netherlands, *Models and Modeling in Science Education*, vol. 3, pp.3–24. Available from: https://doi.org/10.1007/978-1-4020-5267-5_1.
[25] Gilbert, J.K. and Boulter, C.J., eds, 2000. *Developing Models in Science Education*. Dordrecht: Springer Netherlands. Available from: https://doi.org/10.1007/978-94-010-0876-1.
[26] Gökçek, Y. and Zorlu, Y., 2020. Öğretmen Adaylarının Model ve Modelleme ile Yaşam Becerilerine Ait Görüşlerinin Bilişötesi Farkındalıklarıyla Arasındaki İlişkilerin İncelenmesi [Investigation of the relationship between prospective teachers' views on models and modeling life skills and their metacognitive awareness]. *Mediterranean Educational Research Journal*, 14(33), pp.206–221. Available from: https://doi.org/10.29329/mjer.2020.272.10.
[27] Güneş, B., Gülçiçek, Ç. and Bağcı, N., 2004. Eğitim fakültelerindeki fen ve matematik öğretim elemanlarının model ve modelleme hakkındaki görüşlerinin incelenmesi [Investigation of science and mathematics education faculty members' views on model and modeling]. *Journal of Turkish Science Education*, 1(1), pp.35–48. Available from: https://mail.tused.org/index.php/tused/article/view/39/15.
[28] Harrison, A.G. and Treagust, D.F., 2000. A typology of school science models. *International Journal of Science Education*, 22(9), pp.1011–1026. Available from: https://doi.org/10.1080/095006900416884.
[29] Kafai, Y.B. and Burke, Q., 2015. Constructionist Gaming: Understanding the Benefits of Making Games for Learning. *Educational Psychologist*, 50(4), pp.313–334. Available from: https://doi.org/10.1080/00461520.2015.1124022.
[30] Landis, J.R. and Koch, G.G., 1977. The Measurement of Observer Agreement for Categorical Data. *Biometrics*, 33(1), pp.159–174. Available from: https://doi.org/10.2307/2529310.
[31] Louca, L.T. and Zacharia, Z.C., 2012. Modeling-based learning in science education: cognitive, metacognitive, social, material and epistemological contributions. *Educational Review*, 64(4), pp.471–492. Available from: https://doi.org/10.1080/00131911.2011.628748.
[32] Malone, K.L., 2023. The effects of modeling-based pedagogy on conceptual understanding, scientific reasoning skills, and attitudes towards science of English learners. *Science Education*, 107(5), pp.1269–1301. Available from: https://doi.org/10.1002/sce.21805.
[33] Malone, K.L., Schunn, C.D. and Schuchardt, A.M., 2018. Improving Conceptual Understanding and Representation Skills Through Excel-Based Modeling. *Journal of Science Education and Technology*, 27(1), pp.30–44. Available from: https://doi.org/10.1007/s10956-017-9706-0.
[34] Margolin, J., Pinerua, I. and Gerdeman, D., 2022. *Modeling in Science Education: A Synthesis of Recent Discovery Research PreK-12 Projects*. American Institutes for Research. Available from: https://par.nsf.gov/biblio/10358422.

[35] Nielsen, S.S. and Nielsen, J.A., 2021. A Competence-Oriented Approach to Models and Modelling in Lower Secondary Science Education: Practices and Rationales Among Danish Teachers. *Research in Science Education*, 51(2), pp.565–593. Available from: https://doi.org/10.1007/s11165-019-09900-1.
[36] Oh, P.S. and Oh, S.J., 2011. What Teachers of Science Need to Know about Models: An overview. *International Journal of Science Education*, 33(8), pp.1109–1130. Available from: https://doi.org/10.1080/09500693.2010.502191.
[37] Palinkas, L.A., Horwitz, S.M., Green, C.A., Wisdom, J.P., Duan, N. and Hoagwood, K., 2015. Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research. *Administration and Policy in Mental Health and Mental Health Services Research*, 42(5), pp.533–544. Available from: https://doi.org/10.1007/s10488-013-0528-y.
[38] Papadakis, S., Kiv, A.E., Kravtsov, H.M., Osadchyi, V.V., Marienko, M.V., Pinchuk, O.P., Shyshkina, M.P., Sokolyuk, O.M., Mintii, I.S., Vakaliuk, T.A., Azarova, L.E., Kolgatina, L.S., Amelina, S.M., Volkova, N.P., Velychko, V.Y., Striuk, A.M. and Semerikov, S.O., 2022. Unlocking the power of synergy: the joint force of cloud technologies and augmented reality in education. In: S.O. Semerikov and A.M. Striuk, eds. *Joint Proceedings of the 10th Workshop on Cloud Technologies in Education, and 5th International Workshop on Augmented Reality in Education (CTE+AREdu 2022), Kryvyi Rih, Ukraine, May 23, 2022*. CEUR-WS.org, *CEUR Workshop Proceedings*, vol. 3364, pp.1–23. Available from: https://ceur-ws.org/Vol-3364/paper00.pdf.
[39] Papadakis, S., Kiv, A.E., Kravtsov, H.M., Osadchyi, V.V., Marienko, M.V., Pinchuk, O.P., Shyshkina, M.P., Sokolyuk, O.M., Mintii, I.S., Vakaliuk, T.A., Striuk, A.M. and Semerikov, S.O., 2022. Revolutionizing education: using computer simulation and cloud-based smart technology to facilitate successful open learning. In: S. Papadakis, ed. *Joint Proceedings of the 10th Illia O. Teplytskyi Workshop on Computer Simulation in Education, and Workshop on Cloud-based Smart Technologies for Open Education (CoSinEi and CSTOE 2022) co-located with ACNS Conference on Cloud and Immersive Technologies in Education (CITEd 2022), Kyiv, Ukraine, December 22, 2022*. CEUR-WS.org, *CEUR Workshop Proceedings*, vol. 3358, pp.1–18. Available from: https://ceur-ws.org/Vol-3358/paper00.pdf.
[40] Patton, M.Q., 2002. *Qualitative Research and Evaluation Methods*. 3rd ed. Sage Publications. Available from: https://aulasvirtuales.wordpress.com/wp-content/uploads/2014/02/qualitative-research-evaluation-methods-by-michael-patton.pdf.
[41] Prins, G.T., Bulte, A.M.W. and Pilot, A., 2011. Evaluation of a Design Principle for Fostering Students' Epistemological Views on Models and Modelling Using Authentic Practices as Contexts for Learning in Chemistry Education. *International Journal of Science Education*, 33(11), pp.1539–1569. Available from: https://doi.org/10.1080/09500693.2010.519405.
[42] Ruebush, L., Sulikowski, M. and North, S., 2009. A Simple Exercise Reveals the Way Students Think About Scientific Modeling. *Journal of College Science Teaching*, 38(3), pp.18–22. Available from: https://www.jstor.org/stable/42993571.
[43] Sadler, T.D., 2009. Situated learning in science education: socio-scientific issues as contexts for practice. *Studies in Science Education*, 45(1), pp.1–42. Available from: https://doi.org/10.1080/03057260802681839.
[44] Schwarz, C.V., Reiser, B.J., Davis, E.A., Kenyon, L., Achér, A., Fortus, D., Shwartz, Y., Hug, B. and Krajcik, J., 2009. Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, 46(6), pp.632–654. Available from: https://doi.org/10.1002/tea.20311.

[45] Şimşek, F. and Hamzaoğlu, E., 2020. Modellerle Zenginleştirilmiş Fen Öğretiminin Akademik Başarı, Kalıcılık ve Tutum Üzerine Etkisi [The Effects of Science Teaching Enriched with Models on Academic Achievement, Knowledge Retention and Attitudes Towards Science]. *Kastamonu Education Journal*, 28(3), pp.1333–1344. Available from: https://doi.org/10.24106/kefdergi.3899.

[46] Smith, J., 1996. Mathematical Modelling. *Mathematics in School*, 25(4), pp.14–17. Available from: https://www.jstor.org/stable/30216577.

[47] Taber, K.S., 2017. Models and Modelling in Science and Science Education. In: K.S. Taber and B. Akpan, eds. *Science Education: An International Course Companion*. Rotterdam: SensePublishers, New Directions in Mathematics and Science Education, pp.263–278. Available from: https://doi.org/10.1007/978-94-6300-749-8_20.

[48] Tanner, K.D., 2010. Order Matters: Using the 5E Model to Align Teaching with How People Learn. *CBE—Life Sciences Education*, 9(3), pp.159–164. Available from: https://doi.org/10.1187/cbe.10-06-0082.

[49] Tasquier, G., Levrini, O. and Dillon, J., 2016. Exploring students' epistemological knowledge of models and modelling in science: results from a teaching/learning experience on climate change. *International Journal of Science Education*, 38(4), pp.539–563. Available from: https://doi.org/10.1080/09500693.2016.1148828.

[50] Treagust, D.F., Chittleborough, G. and Mamiala, T.L., 2002. Students' understanding of the role of scientific models in learning science. *International Journal of Science Education*, 24(4), pp.357–368. Available from: https://doi.org/10.1080/09500690110066485.

[51] Tunnicliffe, S.D. and Reiss, M.J., 2000. Building a model of the environment: how do children see plants? *Journal of Biological Education*, 34(4), pp.172–177. Available from: https://doi.org/10.1080/00219266.2000.9655714.

[52] Ünal, S. and Benzer, A.İ., 2021. Modelleme temelli öğrenme: Türkiye'de 2004-2019 yılları arasından yayımlanmış makalelerin içerik analizi [Modeling-based learning: A content analysis of articles published in Turkey between 2004-2019]. *Atatürk Üniversitesi Kazım Karabekir Eğitim Fakültesi Dergisi*, (42), pp.185–206. https://dergipark.org.tr/tr/download/article-file/1463758, Available from: https://doi.org/10.33418/ataunikkefd.845523.

[53] Vosniadou, S., 1994. Capturing and modeling the process of conceptual change. *Learning and Instruction*, 4(1), pp.45–69. Available from: https://doi.org/10.1016/0959-4752(94)90018-3.

[54] Xue, S., Topping, K., Lakin, E. and Krell, M., 2025. Modelling Competence in Teacher Education: Comparing Meta-modelling Knowledge, Modelling Practices and Modelling Products Between Pre-service and In-service Teachers. *Research in Science Education*, 55(2), pp.253–275. Available from: https://doi.org/10.1007/s11165-024-10183-4.

[55] Yilmaz, O., 2021. Augmented Reality in Science Education: An Application in Higher Education. *Shanlax International Journal of Education*, 9(3), pp.136–148. Available from: https://doi.org/10.34293/education.v9i3.3907.

A. Distribution of modelling approaches by grade level, topic, and timeframe

Weeks	Grade	Topic	Modelling activity	Modelling approach
1-6	5	Moon movements and phases	Moon phases model	Physical model
1-4	6	Solar system and eclipses	Planet model made from clay	Physical model
1-4	7	Solar system and beyond	Examination of lenses	Physical model
7-10	5	World of living things	Examination of fungi	Sensory modelling
5-10	6	Systems in our body	Bone-kidney-heart examination, skeleton construction, 4D skeleton examination, digestive system breakfast, digestive system song video	Sensory modelling, design-based and physical modelling, computer simulation modelling, drama-based and physical modelling, visual and conceptual modelling
5-8	7	Cell and divisions	Onion skin and oral epithelium microscope examination, cell cake making	Sensory modelling, analogical modelling
11-13	5	Force measurement and friction	Dynamometer construction, friction track construction, parachute construction	Design-based and physical modelling, experimental modelling, design-based and experimental modelling
11-13	6	Force and motion	Resultant force with blocks	Physical modelling
9-13	7	Force and energy	Friction track construction, parachute construction	Experimental and design-based modelling
14-19	5	Matter and change	States of matter drawing, phase change mask	Visual and conceptual modelling, analogical modelling
14-20	6	Matter and heat	Density tower, mandarin experiment	Visual and experimental modelling, experimental and sensory modelling
14-20	7	Pure substances and mixtures	Elements bingo, examination of real elements, students separating their own mixtures	Game-based modelling, sensory modelling, experimental modelling
20-24	5	Light propagation and complete shadow	Light reflection experiment, shadow puppet play	Experimental modelling, drama-based modelling
21-26	6	Sound and its properties	Cup telephone, sound insulated house	Physical and analogical modelling, design-based modelling
21-26	7	Light-matter interaction	Color wheel, how materials appear under different colors experiment	Physical and visual modelling, experimental and sensory modelling
25-30	5	Humans and environment	Exploring the environment observation	Sensory modelling
27-30	6	Our body systems and health	Let’s test our sense organs game	Game-based and sensory modelling

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Weeks	Grade	Topic	Modelling activity	Modelling approach
31-33	5	Electrical circuit components	Simple circuit construction, conductive wire touch-the-lamp game	Design-based and physical modelling, game-based and physical modelling
31-33	6	Transmission of electricity	Simple circuit construction, conductive wire touch-the-lamp game	Design-based and game-based modelling
32-33	7	Electrical circuits	Building series and parallel circuits	Design-based and experimental modelling