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ORIGINAL PAPER

Developing a Tic-Tac-Toe-Based Board Game for Learning Trigonometry: An ADDIE-Oriented Educational Design Study

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Abstract
This study developed and evaluated the initial feasibility of Make the Sequence, a physical board game adapted from tic-tac-toe to support Grade 11 students' engagement with trigonometry. The product was designed in response to teachers' need for reusable, low-technology learning media that connect problem-solving, peer explanation, and strategic play. The study used an educational research-and-development design organized through the ADDIE model. The analysis phase identified trigonometric functions, the sine and cosine rules, and trigonometric equations as topics requiring more interactive practice. The design and development phases produced an 8 x 8 magnetic board, team chips, 64 trigonometry problem cards, special action cards, and a facilitator guide. The prototype was reviewed by a mathematics content expert and a media design expert, then tested with 24 Grade 11 students. Expert validation indicated that the prototype was appropriate for classroom use after minor revisions related to title visibility and board-edge contrast. Classroom observations showed that the game supported turn-taking, visible participation, peer discussion, and facilitator-guided feedback during problem solving. Because the study did not use a control group or a pretest-posttest achievement measure, the findings are interpreted as evidence of content validity, usability, and classroom feasibility rather than as evidence of learning effectiveness. The article contributes a replicable design specification and formative evaluation argument for future studies of non-digital game-based learning in secondary mathematics.

Keywords:
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Trigonometry
Mathematics Education
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INTRODUCTION

Trigonometry is a central topic in secondary mathematics because it connects geometric reasoning, algebraic manipulation, functional thinking, and applications in science and technology. Despite this importance, many learners experience trigonometry as a fragmented collection of formulas rather than as a system of relationships among angle measure, ratios, periodicity, and contextual quantities. Weber (2005) showed that students may correctly execute procedures with trigonometric functions while still lacking flexible conceptual understanding. This problem is pedagogically important because procedural performance alone does not guarantee that students can interpret, represent, or apply trigonometric relationships in unfamiliar situations.

One persistent classroom challenge is that formula-heavy trigonometry lessons can become dominated by teacher explanation and repetitive exercises. Such routines may provide procedural exposure, but they may not create enough opportunities for students to discuss alternative strategies, test

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conjectures, justify answers, or receive immediate feedback on their reasoning. Mathematics education research has long emphasized that meaningful mathematical understanding is supported when students interact with representations, explain ideas, and participate in tasks that make reasoning visible (Ainsworth, 1999; Boaler, 1998). A practical implication is that teachers need instructional media that are not merely decorative, but that reorganize classroom activity around mathematical engagement.

Game-based learning offers one response to this challenge when game mechanics are deliberately aligned with learning goals. Educational games are most valuable not because they make lessons entertaining, but because rules, goals, feedback, challenge, and interaction can be designed to direct attention toward disciplinary thinking (Plass et al., 2015). Meta-analytic evidence on digital and serious games indicates that games can support cognitive and motivational outcomes when they include clear objectives, appropriate feedback, instructional guidance, and integration of gameplay and content (Clark et al., 2016; Sitzmann, 2011; Wouters et al., 2013). These principles also apply to physical board games, where students must solve mathematical problems before they can progress.

Physical board games are particularly relevant for classrooms where technology access is uneven or where teachers require media that can be reused without internet connectivity. A board game can operate as a concrete representational system: students manipulate cards, chips, and board positions while negotiating answers with peers. Evidence on mathematics manipulatives indicates that concrete materials can support learning when they are meaningfully connected to instructional goals and accompanied by teacher guidance (Carbonneau et al., 2013). Thus, a mathematics board game should not treat play as a reward after learning; instead, the mathematical task should become the condition for making a move.

The design of such media must also consider engagement, motivation, feedback, and cognitive load. The ICAP framework suggests that students are more likely to learn deeply when they move beyond passive reception toward active, constructive, and interactive engagement (Chi & Wylie, 2014). Self-determination theory further suggests that learning environments are more motivating when they support competence, autonomy, and relatedness (Ryan & Deci, 2000). In a guided board-game setting, competence can be supported through solvable but challenging cards, autonomy through strategic placement choices, and relatedness through team-based discussion. At the same time, feedback must clarify whether a response is correct and why, because feedback is most useful when it helps learners understand goals, progress, and next steps (Hattie & Timperley, 2007).

The design must avoid the opposite risk: assuming that play alone produces accurate mathematical understanding. Research on minimally guided instruction warns that learners may become overloaded or form incorrect understandings when tasks are insufficiently scaffolded (Kirschner et al., 2006). Cognitive-load research also shows that unclear visual elements can consume attention that should otherwise be used for learning (Mayer & Moreno, 2003). For this reason, the game described in this study was designed as a guided practice and consolidation medium rather than as a replacement for teacher explanation. Its visual layout, rules, answer-checking procedure, and facilitator guide were treated as core design elements.

This study developed Make the Sequence, a tic-tac-toe-inspired board game for Grade 11 trigonometry. Unlike ordinary 3 x 3 tic-tac-toe, the prototype uses an 8 x 8 magnetic board and requires teams to answer trigonometry problems before placing chips. A team wins by aligning five chips horizontally, vertically, or diagonally. The study was guided by two research questions: (1) How can a tic-tac-toe-based board game be designed to support Grade 11 trigonometry learning? (2) What evidence of expert validity, usability, and classroom feasibility is obtained from the initial evaluation of the prototype?

METHODOLOGY

Research Design

This study used an educational research-and-development design organized through the ADDIE framework: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The study also follows the logic of design-based research because it produced an educational artifact, tested the artifact in an authentic classroom context, and used formative evidence to refine the design (Baumgartner et al, 2003). The scope of this study was limited to prototype development, expert validation, and initial classroom feasibility testing.

The study is therefore best classified as a formative educational design study rather than an experimental effectiveness study. The available evidence supports claims about the appropriateness, usability, and feasibility of the prototype. It does not support causal claims about achievement improvement because no controlled comparison or validated pretest-posttest measure was used.

Context and Participants

The needs analysis was conducted through interviews with Grade 11 mathematics teachers. The classroom try-out involved 24 Grade 11 students at a public senior high school in Jakarta, Indonesia. Students were organized into four teams during the try-out. Two experts participated in the validation stage: one expert in mathematics content and one expert in media design.

The study reported product-validation evidence and classroom-observation evidence. No individual student achievement scores or personally identifiable student data are reported in this manuscript.

Product Specification

The sequence consists of a foldable magnetic board, team chips, trigonometry problem cards, special action cards, and a facilitator guide. Table 1 summarizes the product specification and the intended instructional function of each component.

Table 1. Product specification of Make the Sequence

Component	Specification	Instructional function
Board	8 x 8 grid; approximately 60 cm x 68 cm; foldable; magnetic surface.	Displays strategic positions and makes team progress visible to the class.
Team chips	Four visual themes; 16 magnetic chips per team.	Supports group identity and the physical placement of correct answers.
Problem cards	64 color-coded trigonometry cards with item numbers.	Requires students to solve trigonometry problems before making moves.
Special cards	Tic-Tac-Toe cards; four of each type.	Adds uncertainty and strategic variation while maintaining rule-based play.
Facilitator guide	Game description, rules, content summary, answer key, and implementation sequence.	Supports teacher guidance, feedback, and classroom implementation consistency.

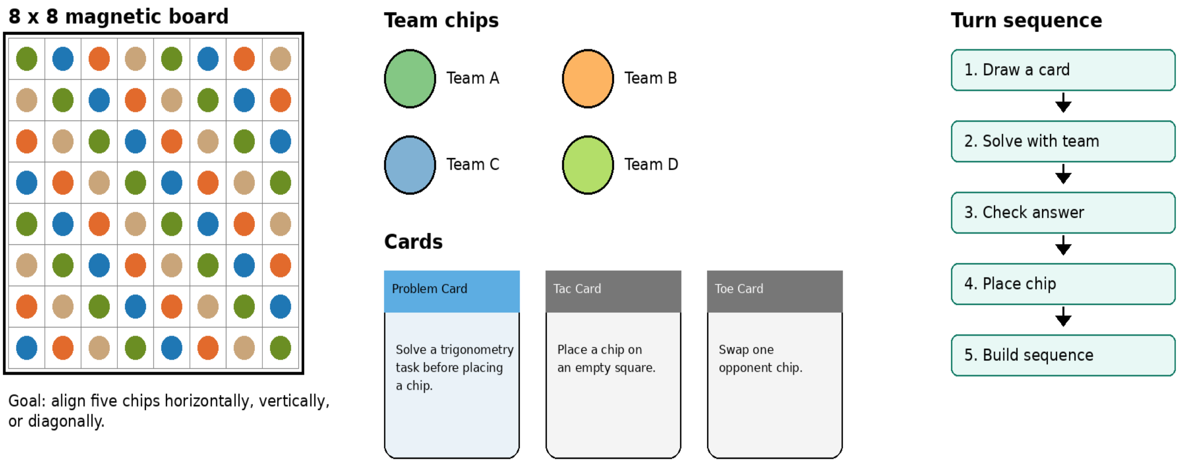

Figure 1. Schematic of the Game Components and Turn Sequence.

Development Procedures

1. **Analysis.** Teacher interviews were used to identify classroom needs, difficult subtopics, and available learning media. Trigonometric functions, the sine and cosine rules, and trigonometric equations were selected because teachers identified them as demanding topics for students.
2. **Design.** The prototype was drafted using presentation software. The design included the board layout, color-coded spaces, card templates, chip visuals, and facilitator rules.
3. **Development.** The physical prototype was constructed and reviewed by the mathematics content expert and the media design expert. The experts rated the prototype on a 1-5 scale and provided qualitative comments.
4. **Implementation.** The revised prototype was tried out with 24 students in four teams. Students drew cards, solved the problems collaboratively, reported answers to the facilitator, and placed chips when their answers were correct.
5. **Evaluation.** Expert comments and classroom observations were used to revise the prototype. The most visible revisions were improving the contrast of the board title and adding a darker outline to the board edges.

Data Collection and Analysis

Data sources included teacher interview notes, expert validation sheets, product photographs, and classroom observation notes. Expert ratings were interpreted descriptively because only two experts participated. Qualitative comments were categorized as evidence related to content alignment, visual readability, usability, and rule clarity.

Following contemporary validity thinking, validation was treated as an evidence-based argument about the appropriate use of the prototype rather than as a permanent property of the product alone (Messick, 1995). The analysis, therefore, focused on whether the prototype was sufficiently aligned with the Grade 11 trigonometry content, sufficiently usable for classroom implementation, and sufficiently clear for guided team practice.

RESULTS & DISCUSSION

Results

Needs Analysis

Teacher interviews revealed that students often experienced difficulties sustaining attention during conventional teacher-led explanations and individual practice activities, particularly when learning topics such as trigonometry that require students to work with multiple formulas, relationships, and procedural steps. Teachers observed that students tended to become less engaged when instruction relied heavily on verbal explanations, textbook exercises, and repetitive formula application. In such situations, students could follow the teacher's explanation at the beginning of the lesson but gradually lose concentration when they were required to practice independently. Teachers also reported that the instructional media available in their classrooms were generally limited to presentation slides, textbooks, internet-based resources, and direct teacher explanations. Although these resources were useful for delivering conceptual information and examples, they provided relatively limited opportunities for students to interact with the content, collaborate with peers, and repeatedly practice procedures in an engaging context.

These findings highlighted the need for an instructional medium that could complement existing classroom practices without requiring sophisticated technological infrastructure. Accordingly, the proposed medium was designed as a low-technology, reusable, and interactive learning resource that could be implemented repeatedly across different learning sessions. Rather than replacing teacher explanations, the medium was intended to redistribute the learning process by shifting part of the lesson from teacher-centered explanation toward structured and guided team practice. Through this approach, students would have opportunities to discuss problems, make decisions, apply trigonometric procedures, check their understanding, and learn from their peers while the teacher remained responsible for providing guidance and clarification. The needs analysis therefore emphasized not only the content to be delivered but also the type of learning experience required to improve student engagement and participation.

The needs analysis also established that the game should not be positioned as an independent method for introducing trigonometric concepts. Trigonometry involves prerequisite knowledge and interconnected concepts, including angle relationships, ratios, formulas, and problem-solving procedures. Therefore, asking students to discover or learn these concepts solely through gameplay could create unnecessary cognitive demands and potentially reduce the effectiveness of the activity. Instead, the game was conceptualized as a consolidation and reinforcement activity to be implemented after students had received formal instruction and had been introduced to the relevant concepts, formulas, and procedures. In this role, the game would provide students with an opportunity to revisit and apply previously learned material in a more interactive and collaborative setting.

This decision subsequently influenced several aspects of the instructional design, particularly the development of the facilitator guide and the answer-checking procedure. The facilitator guide was designed to clarify when and how the game should be introduced, what prerequisite knowledge students should possess, how teams should participate, and how the teacher should provide guidance without dominating the activity. Similarly, the answer-checking procedure was structured to ensure that gameplay remained academically meaningful rather than becoming merely a competitive activity. By incorporating systematic checking and opportunities for clarification, the game could reinforce correct procedures, identify misunderstandings, and encourage students to reflect on their answers. Thus, the needs analysis ultimately positioned the game as a complementary instructional medium that connects prior teacher-led instruction with active, collaborative, and repeated practice of trigonometric concepts.

Prototype Design

The initial prototype transformed tic-tac-toe into a larger sequence-building game. The 8 x 8 grid expanded strategic possibilities and made the game suitable for group play. The magnetic board allowed the game to be played upright, making the state of play visible to all teams. The design avoided overloading the board with mathematical symbols; the mathematical demand was placed on the problem cards, while the board represented the game state and strategic movement.

The problem cards were central to the instructional design. Students could not place a chip simply because it was their turn. They had to solve a trigonometry item first, report the answer, and receive facilitator confirmation. This mechanism linked game progression to mathematical work and reduced the risk that students would treat the activity as unrelated entertainment.

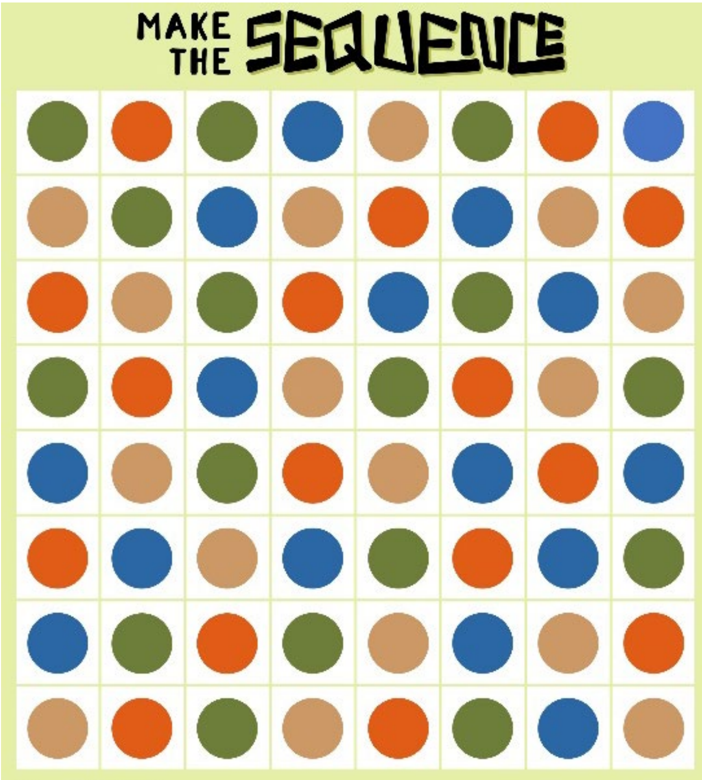

Figure 2. Revised Board Layout with Improved Title Visibility and Edge Contrast

Expert Validation

The content expert judged that the learning objectives, item content, and trigonometry scope were appropriate for Grade 11 use. The media expert judged that the game was usable and visually engaging and recommended visual revisions to improve readability. Table 2 summarizes the validation evidence and the revisions made to the prototype.

Table 2. Summary of Expert Validation and Prototype Revision

Aspect	Evidence from validation	Revision required	Revision made
Content alignment	Objectives, competencies, and problem cards were judged appropriate for the target topic and grade level.	No substantive content revision was requested.	Content was retained and organized in the facilitator guide.
Readability	Most text and layout indicators were rated good or very good.	The board title needed a stronger contrast.	The title color was changed to black.
Visual design	Images and colors were considered attractive for classroom use.	Board edges needed a clearer definition.	A darker outline was added to the board edges.
Usability	Rules and game flow were considered manageable for classroom implementation.	Facilitator guidance is needed to remain explicit.	The guide and answer key were included in the product package.

Classroom Try-Out

During the try-out, students worked in teams to solve card-based trigonometry problems before placing chips on the board. Observation notes indicated that students discussed answers with teammates, monitored other teams' positions, and showed visible interest in the winning condition. Figure 3 shows the prototype's classroom use.

The tryout indicated that the game was feasible as a guided-practice activity. The turn sequence was understandable, the physical components could be managed in a classroom setting, and the competitive goal appeared to sustain students' attention during problem solving. The facilitator role remained important because answer checking, rule enforcement, and brief explanations were needed to keep gameplay aligned with the intended mathematics.

Discussion

The development of Make the Sequence demonstrates how a familiar tic-tac-toe mechanic can be transformed into a medium for mathematics learning when the game rules are deliberately tied to disciplinary tasks. The most important design feature is that mathematical problem-solving is not an add-on to the game; it is the condition for progress. A team cannot place a chip unless it solves a trigonometry card correctly. This structure aligns the learning objective with the game objective, a condition emphasized in the game-based learning literature (Plass et al., 2015). Without such alignment, students may become engaged with competition while ignoring the mathematics. In this prototype, however, strategic play depends on successful mathematical reasoning.

The expert validation findings suggest that the prototype achieved an acceptable level of content alignment and media usability for initial classroom implementation. The content expert did not request substantive changes to the trigonometry scope, indicating that the selected topics and problem-card structure were appropriate for Grade 11 guided practice. The media expert's comments focused mainly on visual clarity, especially title contrast and board-edge definition. Although these revisions appear minor, they are pedagogically meaningful. In a classroom game, students must quickly read visual cues, identify available positions, and follow the movement of chips. Poor contrast can increase extraneous cognitive load and reduce the attention available for mathematical reasoning (Mayer & Moreno, 2003). The revision, therefore, strengthened not only the product's appearance but also its instructional usability.

The classroom try-out provides evidence that the game can support interactive engagement. Students did not merely observe teacher demonstration; they drew cards, solved problems, negotiated answers with teammates, and made placement decisions. This pattern corresponds to the active, constructive, and interactive levels described in the ICAP framework (Chi & Wylie, 2014). Active engagement appeared when students manipulated cards and chips. Constructive engagement appeared when they generated answers and explanations. Interactive engagement appeared when team members discussed possible solutions and coordinated a strategy. These observations are important because trigonometry learning often requires students to connect multiple representations, such as diagrams, ratios, equations, and contextual interpretations. A team-based game can create opportunities for students to verbalize these connections rather than silently perform procedures.

The competitive structure also appears to have motivational value. The goal of aligning five chips gave students an immediate purpose for solving each problem, while the uncertainty of the card draw and the presence of special cards maintained attention. From the perspective of self-determination theory, the activity offered competence support through answerable challenges, autonomy support through strategic placement choices, and relatedness through team collaboration (Ryan & Deci, 2000). However, competition must be interpreted carefully. Competition can motivate participation, but it can also shift attention away from conceptual understanding if the teacher does not facilitate reflection. For this reason, the facilitator guide is not an optional accessory; it is central to the instructional design.

The facilitator role is especially important in trigonometry because student errors often reveal greater conceptual difficulties. A wrong answer may reflect a procedural slip. Still, it may also reflect confusion about angle units, ratio definitions, quadrant signs, inverse trigonometric reasoning, or the conditions for applying the sine and cosine rules. The game creates moments in which these errors become visible, but visibility alone is insufficient. The teacher needs to ask follow-up questions, compare solution strategies, and conduct a short post-game discussion that links moves on the board to the mathematical ideas embedded in the cards. In this sense, Make the Sequence is best understood as a guided consolidation tool rather than as an independent discovery environment. This interpretation is consistent with concerns that minimally guided activities can overload learners when not supported by explicit instruction (Kirschner et al., 2006).

The game's physical format offers practical advantages. It is reusable, device-independent, and visible to the whole group. These features are valuable in schools where digital access is inconsistent or where teachers need media that can be implemented quickly. The magnetic board also solves a common limitation of tabletop board games: when the board stands upright, all teams can monitor progress, and the teacher can manage discussion more easily. At the same time, the physical format has limitations. It does not automatically record student responses, track misconceptions, or adapt item difficulty. Future versions could combine the board with a simple response log or digital scoring sheet. Such an extension should be carefully designed so that the technology supports, rather than replaces, the peer discussion that made the prototype feasible.

The results also clarify the level of claim that can be responsibly made. The prototype is considered valid, usable, and feasible for guided trigonometry practice, based on expert review and classroom observation. It should not yet be described as effective for improving achievement because effectiveness requires stronger evidence, such as a validated trigonometry test, a pretest-posttest design, comparison with conventional practice, and analysis of learning retention. This distinction is important for publication because overclaiming can weaken the credibility of an educational design study. The present study contributes a tested prototype and a design rationale; subsequent studies should investigate learning outcomes and the quality of mathematical discourse during gameplay.

Overall, the study shows that a non-digital board game can be designed to address a real instructional need in secondary mathematics. The value of Make the Sequence lies in its integration of trigonometry problems, strategic placement, team discussion, and facilitator feedback. Its contribution is not to replace formal instruction, but to provide a structured environment for students to practice and discuss trigonometry in a more participatory manner. This makes the prototype a promising basis for further research on low-technology game-based learning in mathematics classrooms.

CONCLUSION

This study developed Make the Sequence, a tic-tac-toe-based board game for Grade 11 trigonometry, using an ADDIE-oriented educational design process. The product includes an 8 x 8 magnetic board, team chips, trigonometry problem cards, special action cards, and a facilitator guide. Expert validation indicated that the prototype was appropriate after minor visual revisions, and classroom observations indicated that the game was feasible for guided team practice.

The most defensible conclusion is that Make the Sequence is a valid and usable prototype for supporting interactive trigonometry practice. The design is promising because it ties every game move to mathematical problem solving, supports peer discussion, and allows teachers to provide immediate feedback. Future research should examine its effect on conceptual understanding, procedural fluency, motivation, retention, and collaborative mathematical discourse using stronger quasi-experimental or mixed-methods designs.

LIMITATION AND FUTURE RESEARCH

The study has several limitations. First, the classroom try-out involved one class of 24 students, so the findings cannot be generalized to all Grade 11 trigonometry classrooms. Second, expert validation involved two experts, which is appropriate for formative review but insufficient for broad psychometric validation. Third, the study did not include a comparison group, a pretest-posttest measure, or a delayed retention test. Fourth, student engagement was interpreted from classroom observations rather than from a validated motivation or engagement instrument.

Future research should address these limitations by testing the game across multiple schools, using validated trigonometry assessments, comparing it with conventional guided practice, and analyzing student dialogue during gameplay. Research should also examine item difficulty, the role of special cards, the optimal group size, and the kinds of teacher prompts that best connect gameplay with trigonometric reasoning.

AI USAGE DECLARATION

The author declares that ChatGPT was used only during the stages of grammar revision and paraphrasing to improve the readability of this article. The author is fully responsible for the substance and accuracy of the content produced.

REFERENCES

Ainsworth, S. (1999). The functions of multiple representations. *Computers & Education*, 33(2-3), 131–152. https://doi.org/10.1016/S0959-4752(99)00029-9

Baumgartner, E., Bell, P., Brophy, S., Hoadley, C., Hsi, S., Joseph, D., Orrill, C., Puntambekar, S., Sandoval, W., & Tabak, I. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, 32(1), 5–8. https://doi.org/10.3102/0013189X032001005

Boaler, J. (1998). Open and closed mathematics: Student experiences and understandings. *Journal for Research in Mathematics Education*, 29(1), 41–62. https://doi.org/10.2307/749717

Branch, R. M. (2009). Instructional design: The ADDIE approach. Springer. https://doi.org/10.1007/978-0-387-09506-6

Carbonneau, K. J., Marley, S. C., & Selig, J. P. (2013). A meta-analysis of the efficacy of teaching mathematics with concrete manipulatives. *Journal of Educational Psychology*, 105(2), 380–400. https://doi.org/10.1037/a0031084

Chi, M. T. H., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist*, 49(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research*, 86(1), 79–122. https://doi.org/10.3102/0034654315582065

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, 77(1), 81–112. https://doi.org/10.3102/003465430298487

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, 41(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, 38(1), 43–52. https://doi.org/10.1207/S15326985EP3801_6

Messick, S. (1995). Validity of psychological assessment: Validation of inferences from persons' responses and performances as a scientific inquiry into score meaning. *American Psychologist*, 50(9), 741–749. https://doi.org/10.1037/0003-066X.50.9.741

Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of game-based learning. *Educational Psychologist*, 50(4), 258–283. https://doi.org/10.1080/00461520.2015.1122533

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, 55(1), 68–78. https://doi.org/10.1037/0003-066X.55.1.68

Sitzmann, T. (2011). A meta-analytic examination of the instructional effectiveness of computer-based simulation games. *Personnel Psychology*, 64(2), 489–528. https://doi.org/10.1111/j.1744-6570.2011.01190.x

Weber, K. (2005). Students' understanding of trigonometric functions. *Mathematics Education Research Journal*, 17(3), 91–112. https://doi.org/10.1007/BF03217423

Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology*, 105(2), 249–265. https://doi.org/10.1037/a0031311