# DIGITAL WALL: A REFLECTIVE TOOL FOR STUDENTS' SELF-REGULATING ONLINE LEARNING WITHIN A PROBLEM-SOLVING APPROACH

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*A digital wall is a tool for students to structure and register their online work on mathematical problem-solving activities that involve the coordinated use of digital technologies. How could students use such digital wall to understand mathematical concepts and to develop problem-solving competencies? The aim of this study is to analyze and document the extent to which the students' use of the wall became a powerful tool to share, discuss, and refine their problem-solving approaches. To this end, the development of the sessions was structured around principles that foster an inquiry method that privileges the participants' formulation of questions; the systematic and coordinated use of digital technologies, and a support system for students to face technical and content questions. Results indicate that the use of a digital wall became a powerful tool for the participants to report and share their ideas and problem-solving approaches to refine and extend their solution methods.*

Keywords: Problem Solving; Online and Distance Education; Technology; Preservice Teacher Education

## An inquiry mathematical problem-solving approach

During the COVID-19 pandemic lockdown, it became clear that students' learning activities might occur not only within a confined classroom, but also be organized and implemented in remote or online spaces through the activation of communication apps and online platforms.

Further, digital apps such as Dynamic Geometry Systems (DGS), have the potential to transform the way students learn about mathematical concepts (Trocki & Hollebrands, 2018) by allowing students to interact in real-time with executable affordances to explore and process mathematical objects attributes actions [Moreno-Armella & Hegedus, 2009]. Thus, we argue that a problem-solving approach where students are asked to use technology's affordances to make conjectures, validate results and explore multiple solutions exploit the potential of learning in online spaces. Santos-Trigo et. al (2022) state that when students work in online scenarios, they can use technology to extend their learning activities that appear in regular classrooms. For instance, they can record their teaching presentations and review them after class sessions, consult online platforms to review concepts, or to interact with peers to discuss or address difficulties that arise during the sessions. Likewise, they can consult online developments to check examples of solved problems. That is, technologies shape the way students engage in mathematical task throughout all problem-solving phases:

In understanding and making sense of problem statements, students could direct their attention to the reconstruction of figures embedded in problem statements and this process might lead them to problem posing activities […] Similarly, representing and exploring dynamically elements of the problem becomes important to identify mathematical relations that lead students to solve the problem […] Furthermore, dynamic models become a source for students to extend and generalize initial conditions and solutions to the problem (Santos- Trigo et al., 2022).

Students learn and develop mathematical ideas when they delve into a diverse type of situations that imply posing and pursuing questions and conceiving their learning process as series of dilemmas that need to be represented, explored and solved in terms of mathematical resources (Santos-Trigo & Reyes-Martínez, 2019). In this perspective, mathematical problems or tasks are a departure point for learners to engage in sense-making activities to understand concepts and to think of different ways to work on and solve those problems (Santos-Trigo & Camacho, 2013). This is, an inquiry problem-solving approach is essential for learners to understand mathematical concepts and to develop problem-solving proficiency: How do students develop and inquiry method to work on mathematical tasks? What questions should they pose and pursue during their understanding of mathematical concepts?

One of the greatest challenges we faced as a result of social long confinement was the limited research results to support the teachers' decisions and actions to frame online teaching and learning environments. In this context, teachers experienced difficulties to select and implement the use of online resources, ways to provide cognitive and social support for students in online spaces, and to assess and give feedback to students (Johns & Mills, 2021; Martin et al., 2020; Trenholm et al., 2015); Within online learning spaces, teachers have less access to subtle cues about student's level of engaging, such as insight or "aha!" moments, limiting opportunities to offer guidance and correct feedback (Mullen, et al., 2021). That is, when thinking about fostering the interaction between students and teachers in online spaces, traditional means of communication are not effective to assess students' concept understanding.

Engelbrecht et al. (2020) points out that online spaces can become favorable spaces for learning when participants share information, tools, and resources constantly. In this sense, a digital wall can be used as a tool that exploits technology's affordances to help students register and reflect upon their own learning experiences: what websites do they check when approaching a mathematical task? What are the definitions that students consider important? How do they control their own work? In other words, a digital wall is a conceptual instrument that provides a way to structure and follow up students problem-solving performances. That is, the research question that guides the development of this study was: To what extent did the students use of a digital wall become a reflective tool for them to register their work and to understand concepts and to develop their problem-solving competencies?

**Conceptual framework**

A digital wall as a tool to organize and structure problem solving activities is based on three intertwined elements: an inquiry problem-solving approach, the use of digital technologies and the role of tasks to engage students in mathematical discussions (Santos-Trigo et. al., 2022).

Since DGS offer a set of affordances for learners to think of multi-representations of mathematical knowledge (Leung, 2017), problem-solving activities within dynamic environments can be oriented towards exploration, rather than focusing on finding one single solution to a problem. Thus, students can use a DGS to analyze and investigate connections between similar problems or to think of how different mathematical concepts can be used to represent, explore, and solve a problem in a variety of ways. Thus, tasks are key for mathematical discussions, and they become a vehicle for students to reflect upon their own knowledge when they approach them. That is, the type of tasks and the way they are implemented in a learning setting are crucial for students to understand concepts and develop their mathematical thinking. In this context, questions that lead students to conjecture, pose problems and to look for generalizations, are essential for students to delve into central mathematical practices (Schoenfeld, 2020).

How should students organize their work when using a digital wall to register, communicate and reflect on their own learning? Santos-Trigo and Camacho (2013) proposed four stages that characterize the ways of reasoning that emerge when students use digital technologies to solve mathematical tasks: (1) Making sense of the problem, that is, using technology to grasp a general idea of what the solution of a problem might involve; (2) using digital tools, such as Geogebra, to explore and formulate conjectures or possible objects' relationships; (3) finding arguments that justify, refute, or validate conjectures and hypotheses; and, (4) looking back at the problem to identify mathematical connections, extend the problem or pose new related questions. The conceptual framework that supports the use of a digital wall and allows it to connect with an inquiry problem-solving approach to learn mathematics is an adjusted version of the RASE conceptual framework (Churchill et. al., 2016), that distinguishes three intertwined dimensions: resources, activities (problem-solving approach), and support (Figure 1).

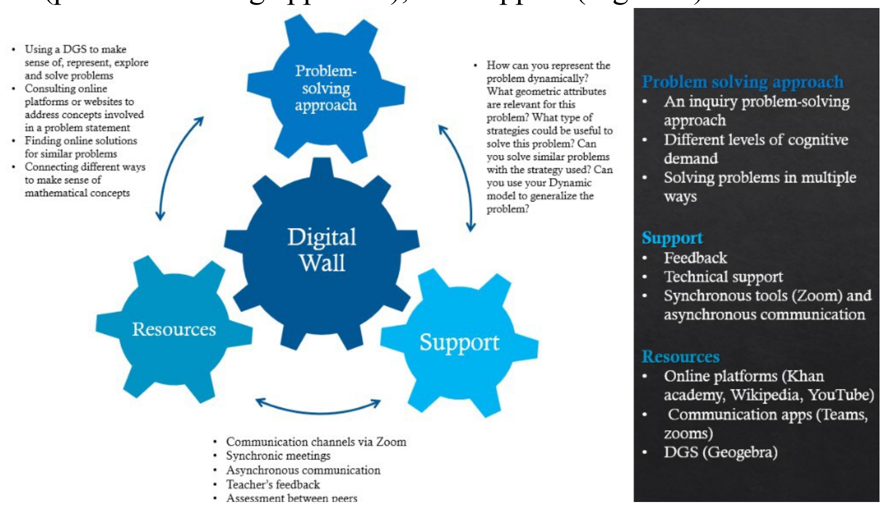



**Figure 1. A framework to structure a digital wall within a problem-solving approach.**

**A problem-solving approach to support mathematical learning.** By conceiving the discipline as a set of sense-making activities, students are encouraged to pose and pursue questions to delve into concepts and solve problems in multiple ways. A mathematical task is only a departure point into developing mathematical thinking. This will characterize the way in which activities are to be implemented and assessed.

**Learning resources.** Schoenfeld described a model to explain students' performance in goal- oriented activities, such as problem-solving, in terms of three categories: resources, goals and decision-making. In online spaces, students' use of digital technologies permeates the way in which sub-goals and self-monitoring occur when they deal with mathematical tasks. That is, resources are not only to be considered in the way Schoenfeld (2011) originally described, but also how students use technology (i.e., DGS, online platforms, YouTube videos) to represent, explore, extend, and make sense of mathematical problems, as well as to share and convey their results.

**Online support.** This support includes teachers' feedback, spaces for sharing ideas and solutions like forums, messenger apps, and online meetings. It includes ways to monitor and assess students' understanding of concepts and problem-solving performances.

## Methodological Elements

Since our main objective is to describe how students exhibit problem-solving abilities by using a digital wall, this study has a qualitative nature. Data were obtained from an 8-weeks problem-solving workshop that was implemented as a part of a mathematics education master program. In this report, we focused on the work of two participants (referred as Hector and Carol). In order to increase the trustworthiness of the data analysis, we included strategies to delve into peer debriefing, triangulation of various types of information and reflexibility of the data (Freitas, 2017). The workshop was conducted fully online, via Microsoft Teams platform and Zoom, for synchronous meetings on a weekly basis.

Participants worked in two episodes: First, they were given a mathematical task in advance, to register their individual work in their digital wall; then, during weekly Zoom meetings (3 hrs. duration), students shared their ideas, solutions, and conjectures with the rest of the group, where they would receive feedback from their peers and workshop coordinators. The guidelines given to the participants to work on the tasks were based on Santos-Trigo and Reyes-Martínez (2018) that involve: (a) Always construct a dynamic model of the problem and explore it to identify conjectures or relationships regarding the objects observed in the model; (b) look for different ways to explore, (c) interpret and solve the mathematical problems; (d) show arguments that justify and support conjectures and hypotheses; (e) change the problem statement's initial conditions of the problem statement to explore or discuss whether the strategies used to solve the original problem can be used to solve similar ones; and, (f) identify, analyze, and contrast concepts, strategies or methods used.

OneNote app was chosen for students to report their work in the digital wall, since it allows the user to create notes with easy, including images, videos and even to embed GeoGebra constructions (at the time where the study was conducted) by including the online link. One *a priori* example of a digital wall in OneNote can be found here. It was suggested to work around three basic sections for each problem: understanding the problem, exploring the dynamic model, and posing new questions regarding the original problem statement (extending the problem).

## Results & Analysis

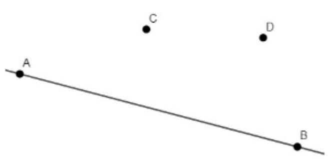
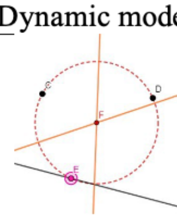
Individual digital walls were the main source of information about the participants' performance throughout the workshop. Given a problem, three main elements from the digital wall were used to characterize participants' performance (Santos-Trigo, et al., 2022):

- Comprehension phase. What types of questions do students pose to understand and delve into problem statement? Do they consult online resources to gain a better understanding of the problem?
- Exploration and solution phase. How are the DGS affordances being used to represent the problem? How do the students incorporate these affordances into problem-solving strategies? What types of conjectures do the students make? How do they support these conjectures? What resources are students activating to work on the task?
- Extension phase. What new questions do students pose to extend the initial problem? Are they investigating to what extent the strategies used can be useful to work and solve new problems? Are they identifying what type of knowledge, concepts, strategies, and resources they used to achieve the problem solution? Can they solve a more general related problem?

Participants were asked to solve Apollonius tangency problems, that is, given three objects (a point, a line, or a circle) draw a circle that is tangent to those three objects (or that passes through, for the case of a point).Whilst these problems have been solved via algebraic methods and ruler-and-compass constructions extensively, by using a DGS students can find novel solutions involving the loci of dragging points in forms of conic sections (Santos-Trigo, et. al, 2021). Solving the Apollonius tangency problems using a DGS involves the activation of the tool affordances to dynamically represent and explore the involved objects behaviors. It also demands that students rely on problem-solving strategies that include simplifying or reducing initial problem conditions to approach particular cases and then to solve the problem. Ten cases or configurations associated with the Apollonio's problem can be dynamically modeled to solve it (Santos-Trigo, et al., 2019). We will now include a discussion about participants' work on three problems.

**Initial case: given two points and a line, how to draw a tangent circle to line AB that passes through points C and D (2P1L problem)?** Prior to work on this problem, students explored how to draw a tangent line to a circle from a point on the circle, and the first 2 cases of Apollonius problems: Drawing a circle that passes through three points (PPP problem) and drawing a tangent circle to three lines (LLL problem). For the 2P1L problem, both Hector and Carol relied on the same strategy, summarized in Table 1. First, participants drew a circle passing through the given points C, D, and through a point E, online AB. This clearly is not a *robust* solution, because this circle is not necessarily tangent to AB. By moving point E, when will the circle become tangent to line AB? This exploration was mainly visual, since participants only moved point E until the circle *seemed* tangent (see step 10 of DM1). Is there another way to support empirically the tangency of the circle? By recalling the construction of a tangent line to a point on a circle, they noticed that if they traced a perpendicular from point E to the given line, the solution should be obtained when they point F lies on the perpendicular line (Step 11, DM1). This, however, was still a mainly empirical solution.

**Table 1: Exploration from Hector & Carol to the 2P1L tangency problem.**

| Initial objects | Dynamic model | Strategy |
|---|---|---|
|  Line AB and points C & D |  Dynamic model 1 (DM1) | Returning to previous problems (CCC and tangent to a circle): Drawing point E on the line AB, then a circle that passes through C, D, and E. What conditions for point E make the circle tangent to the line AB? |

The perpendicular line was a key element considered when giving feedback to Hector in the form of a question: By moving point E, we can see the intersection G of the perpendicular line and the perpendicular bisector of points E and C moving in a particular way as E moves along the line AB. How can we describe this movement (Steps 12-13, DM1)? By using the *locus tool*, a parabola-like curve appears (Figure 2a). Is this curve indeed a parabola? Hector quickly noted that G lies in the perpendicular bisector of CE, thus, the distance from GC is equal to the distance from G to line AB, this is what defines a parabola as a locus with C as the focus and AB as its directrix. What does this locus mean in terms of the problem? Each point on the parabola is the center of a circle tangent to line AB that passes through C. If the same process is done with the perpendicular bisector of points E and D, another parabola can be obtained (Figure 2b): this parabola holds a similar meaning, since it contains the centers of circles tangent to line AB passing through D. How can these parabolas be used to obtain the solution of the problem? The intersections of both parabolas are the centers of circles that are tangent to line AB and that pass through both points D and C (Figure 2c). See Dynamic Model 2 for a full solution.

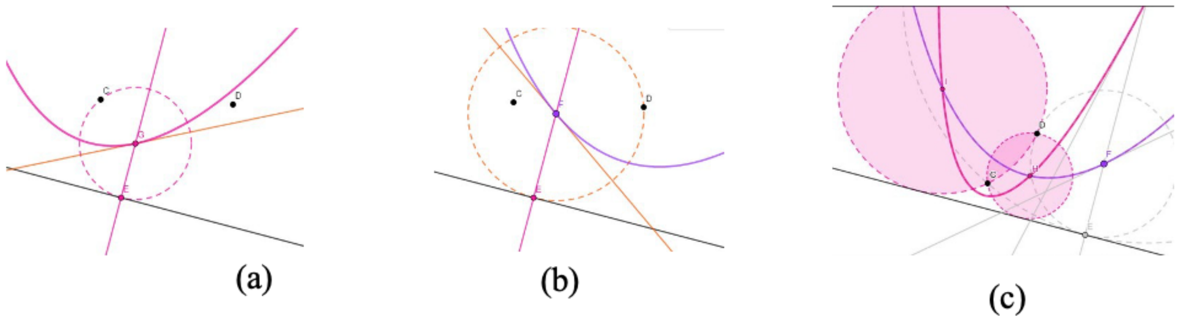
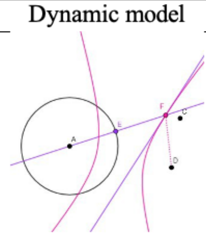
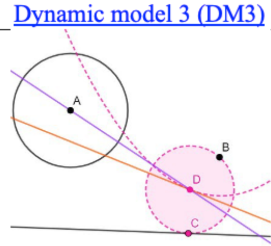



**Figure 2: Using parabolas to solve Problem 2P1L.**

In this first case, the solution demanded the activation of resources like perpendicular lines and perpendicular bisectors. The perpendicular line from E contains all centers of circles that are tangent to line AB at E, while the perpendicular bisector of EC contains all the centers of circles that pass through C and E. The intersection of the perpendicular bisector of CE and the perpendicular line to line AB from point E then gave a partial solution, which was then generalized in the form of a locus (a parabola) that allowed to solve the problem. It was also noted that by simplifying the initial conditions, it was possible to orderly explore this problem to obtain a solution that could be extended to the rest of Apollonius configurations. We will now describe how this strategy was applied by both Hector and Carol in different problems.

**How did students explore more configurations for the tangency problem?** By taking the 2P1L problem as a starting point, students went on to solve other configurations of the tangency problems (see Table 2).

**Table 2: Examples of participant's models for the tangency problem**

| Student | Problem | Dynamic model | Strategy |
|---|---|---|---|
| Hector | Draw a circle tangent to a given circle that passes through two given points (2P1C) |  Dynamic model 3 (DM3) | Returning to a previous problem (2P1L): Draw point E on the given circle. In this case, a "perpendicular line" is translated as the AE line, and then the perpendicular bisector of E and point D gives a point F that is the center of a circle tangent to circle A and passes through D. When will this circle also pass through C? The rest of the solution can be found on the link to Hector's exploration. |
| Carol | Draw a circle tangent to a given line, and a given circle that passes through a given point (1P1L1C) |  Dynamic model 4 (DM4) | Simplifying the initial conditions: Take a point C on the given line, draw the parabola with focus B and directrix the given line. Then, trace the perpendicular bisector of BC. This is tangent to the parabola at point D. A circle with center D that passes through B will also be tangent to the given line. By moving point C, when will this circle be tangent to the given circle? The rest of the solution can be found on the link to Carol's exploration. |

Hector relied upon the solution of the 2P1L by simplifying the initial conditions. First, he conceived that the line in the 2P1L problem was a "circle of infinite radius", and tried to translate the same ideas into the 2P1C problem. That is, he took a point E on the circle given and traced a line passing through A (the center of the given circle) and E, this would be the "perpendicular line"; then, he traced the perpendicular bisector of ED. The intersection of these two lines is a point

F, the center of a circle tangent to the given circle and passing through point D. As point E moves within the given circle, what is the locus of point F? By using the locus tool, we can see that the resulting curve seems like a hyperbola (step 10, DM3).

Hector conjectured that it was indeed a hyperbola and its foci must be points A and D. He justified this conjecture algebraically by noticing that $||AF|-|FD||=¿|AE|+|EF|-|FD|\vee¿$, since $F$ lies on the perpendicular bisector of ED, $|EF|=¿\,FD\vee¿$, thus $||AF|-|FD||=|AE|=r$. Since the difference of distances of any point on this curve to the fixed points A and D is constant ($r$ is the radius of the given circle), it follows that the locus is a hyperbola with foci D and A. Any point on this hyperbola will be the center of a circle that passes through D and is tangent to the given circle. Similarly, repeating the same process for point C gives another hyperbola that contains all centers of circles that pass-through point C and are tangent to the given circle. The intersections of both hyperbolas give the solution (Figure 3). Even further, Hector explored a way to trace the hyperbola using tools from Geogebra by obtaining one of its vertexes, which can be explored in the rest of the steps in DM3. Finally, he explained how all tangency problems can be solved by using a similar strategy: simplifying the initial statement's conditions. That is, by "ignoring" one of the three objects given and trying to find a family of circles that satisfy the conditions for the two remaining objects. Then, a locus that describes a family of solutions can be used for the third object and the solution will be obtained with the intersection of both loci. Although this extension was shared with the rest of the participants, Carol and Val struggled to implement this strategy.

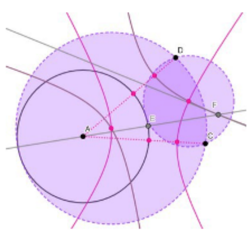


**Figure 3. Using hyperbolas to solve Problem 2C1L.**

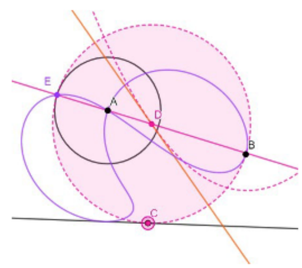


**Figure 4. Carol's attempt to solve Problem 1P1L1C.**

Now, Carol's approach to the 1P1L1L problem is described in Table 2. First, she "ignored" the given circle and focused on finding a family of circles tangent to the given line that pass- through the given point B. By using the results in the 2P1L problem, she drew a parabola with locus B and the given line as the directrix. She then drew a point C on the given line, and used the perpendicular bisector of BC to find the center D of a circle that passes through B and is tangent to the given line at C. By moving point C, Carol visually identified that this newly drawn circle will be tangent to the given circle at some position for point C (step 13 DM4). She then traced the line connecting the center A of the given circle with point D. Then she found the intersection E of line AD with the circle with center D. How does point E moves as C is moved along the given line (step 15 DM4)? Visually, when point E lies on the given circle, a solution is found: the circle with center D is tangent to both given objects and passes through point B. By using the locus tool, Carol expected to find a curve that could be described in geometric terms; alas, when the obtained curved seems too complex to describe in structural terms (Figure 4), however, it allows to see that it has 4 intersections with circle A, and thus, there must be 4 solutions. The point C can be moved manually to "see" these four solutions, but since Geogebra does not allow to find the intersection of geometric objects with curves obtained via the locus tool, a *robust* solution could not be obtained by Carol.

### Concluding Remarks

The use of digital technologies, including online developments, communication apps and DGS, become important to share and extend mathematical discussions as well to open up novel routes for students to represent and explore mathematical problems (Santos-Trigo, et al., 2021). For the Apollonius problems, it became clear that they had to be solved by considering only two of the three objects and characterize the family of centers of circles that satisfy these two conditions. Table 3 summarizes the different loci obtained when considering two of the three objects.

**Table 3: Loci obtained for pairs of objects involved in the tangency problems.**

| Objects | 2 points | 2 lines | 1 point & 1 line | 1 circle & 1 point | 1 circle & 1 line | 2 circles |
|---|---|---|---|---|---|---|
| Locus | Perpendicular bisector | Angle bisector | Parabola | Hyperbola | 2 Parabolas | 2 hyperbolas |

Once the 2P1L and the 2P1C were solved, Hector found ways to solve the rest of the Apollonius problems by characterizing the locus of centers of circles tangent (or pass through) to only 2 objects: a point and a circle (a hyperbola), a line and a circle (two parabolas), and eventually, two circles (two hyperbolas). By studying these simplified versions of the tangency problems, Hector developed a *heuristic* that allowed him to successfully explore and solve the rest of Apollonius' tangency problems. That is, looking into the connections between the mathematical objects involved in a problem is an important step for students to use resources as key tools to solve similar problems. Although Carol was not able to initially solve the tangency problems on her own, she constantly posed questions about the strategies she employed. Rather than focusing on the problem's difficulty or faulty resources, she asked for help to implement problem-solving strategies. Carol explored the problem in a way that allowed her to connect the strategy of simplifying the initial conditions with other problems and attempted to use the locus tool to find *robust* solutions, even though initially she struggled to find a proper way to explore problems in order to find locus that could be described in geometric relations (i.e., the parabola for the 2P1L problem and the hyperbola for the 2P1C problem). Students' abilities to coordinate the use of digital resources into their mathematical understanding on virtual spaces can hinder or enhance the appropriation of problem-solving skills. Synchronous sessions were complementary for the digital wall's work since students were able to share their advances on the tasks and help each other to find new ways to solve and pose new problems; asynchronous work was characterized using online platforms that allowed participants to consult concepts and definitions about geometric loci or construction procedures (like tangent lines to a circle from an external point) that were used as supports for other problems tackled in the workshop.

Digital technologies offer affordances in online spaces that shape what problem-solving skills mean and how mathematical resources can be used in finding alternative ways to explore and discuss classical problems. We argue that the use of digital technologies in problem-solving activities has the potential to transform how mathematics can be conveyed to learners, and a digital wall can serve as a key tool that guides the structure and implementation of online activities.

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