Journal of Learning Spaces
Volume 11, Number 2. 2022

ISSN 21586195

Development and evaluation of an online homework system for high school physics classes

Elife Ceviker
Ohio University

Jesse Strycker
Ohio University

Alex Moody
Athens High School

This case study used a design-based research approach to examine the development and evaluation of an online homework system to support learning and problem-solving in a high school physics course. Emergent themes included challenges of building the system, strengths and weaknesses of it, and the benefits to students. While the system largely met desired outcomes and was well received by the students, concerns were raised about the quality and timeliness of some feedback/scaffolding provided by the system. Development of other such systems may help to support students and teachers during the current and post-COVID educational transition.

Introduction

The importance and value of technology integration have been discussed for decades (see International Society for Technology in Education [ISTE], 2000, 2002; Pellegrino et al., 2007). Despite intermediate calls in the past for improvements (e.g., Bausell & Klemick, 2008; Gray et al., 2010), technology integration remains a priority for the government (U.S. Department of Education [USDOE], 2016, 2017) and private entities (ISTE, 2016a, 2016b). While the calls for more and better technology integrations date back at least two decades, the calls to emphasize and increase Science, Technology, Engineering, and Mathematics (STEM) learning have grown in the last decade. As part of this effort, some governmental (White House Office of Science and Technology Policy, 2018) and private entities (ISTE, 2018) have made STEM learning a priority, emphasizing its need to prepare current students to be active citizens and have the skills required to be part of an ever-changing workforce. These priorities have also overlapped, emphasizing how to best support STEM learning through technology (USDOE, 2019). This project is a form of technology integration and a way to support STEM learning.

While it was not an initial motivation in the creation of this project or study, the long shadow cast on schools and student learning by COVID-19 does impact the reception of this project. The pandemic led to the sudden closure of many schools, impacting over 1.6 billion K-12 students in over 190 countries (UNESCO, 2020). A great deal of research is currently being conducted around the world, which considers many perspectives about teaching and learning during the pandemic, but we may not ultimately know the impact of the school closures, the sudden shift to online learning, and gradual return to face-to-face settings for some time. The design and use of an online homework system (OHS), like the one described in this study, may provide an environment that will help to support teachers and students as they transition to life, teaching, and learning during the gradual fade of and after COVID-19.

The guiding questions for this project were: How might an OHS reduce the strain on an individual teacher to produce resources to both promote problem-solving skill development and practice to support student learning? How could the development and use of an OHS help to support STEM learning and problem-solving, specifically in a physics class? How might students and the teacher react to such a system?

Designing to Solve Problems and Meet Goals

The purpose of design-based research (DBR) is to solve existing problems, evaluate designs in natural settings away from labs, and eventually provide a theoretical or practical

---

Elife Ceviker is an instructional designer at the University of Massachusetts Chan Medical School and a recent graduate of the Innovative Learning Design & Technology Ph.D. program in the Department of Educational Studies at Ohio University.

Jesse Strycker is an Assistant Professor in the Innovative Learning Design & Technology program in the Department of Educational Studies at Ohio University.

Alex Moody is a physics teacher at Athens High School and recently completed his master’s degree in the Innovative Learning Design & Technology program in the Department of Educational Studies at Ohio University.

contribution to the field (Barab & Squire, 2004). Working through multiple iterations of an intervention, having these interventions be examined in real-world settings, collaborating with those in the field such as K-12 teachers, and testing the interventions are essential features of DBR (Anderson & Shattuck, 2012). In other words, DBR researchers focus on processes and examine an educational design within real-world settings such as classrooms and online learning environments through iterative cycles, and then pursue a goal of contribution to theory or practice.

Online Homework Systems

Homework has long been assigned for reviewing content or applying learned skills (Bas et al., 2017). Traditional homework (e.g., paper-and-pencil homework) has drawbacks, including the lack of instant feedback, limited observation of students' progress, and limited practice opportunities. By comparison, OHSs can provide instant feedback, numerous problem-solving attempts, and facilitate faster grading (Lenz, 2010; Mendicino et al., 2009).

Previous studies have examined OHS effectiveness and students' attitudes toward them, with some noting improved student performance from elementary-aged (e.g., Mendicino et al., 2009) to college-aged students (e.g., Zerr, 2007). Although such studies claimed OHSs positively impacted students' performance, other studies (e.g., Lenz, 2010; Smolinsky et al., 2018; Wood & Bhute, 2019) did not find statistically significant differences.

When thinking about technology-enhanced homework systems, it is important to consider if they are Computer-Assisted Instruction (CAI) or an Intelligent Tutoring System (ITS). CAI programs are "specific and hand-crafted for the domain, topic, and students addressed" (Larkin & Chabay, 1992, p.1). By contrast, ITSs are designed to implement "a set of instructional principles sufficiently general enough to provide effective instruction for a variety of teaching tasks" (Larkin & Chabay, 1992, p.2). This study's OHS is a CAI system, specifically hand-crafted for a high school physics course to help with two specific units, with scaffolding elements and using data from it to inform teaching and remediation efforts.

Scaffolding

In this project, the use of the OHS for physics practice problems is meant to increase the students' ability to learn with more scaffolding instead of needing a step-by-step "how-to" approach for each problem. Scaffolding describes the assistance offered to a novice learner to achieve higher, independent levels of performance (West et al., 2019). When first creating essential and difficult skills, processes, and content, teachers use scaffolding to ensure student success (Gibbs, 2014). Students may make mistakes, but teachers help them progress by using feedback, cues, or prompts.

Three characteristics for successful scaffolding were described as contingency, intersubjectivity, and transfer of responsibility (Belland et al., 2017). Contingency means that after evaluating their students' abilities, teachers give support as needed, diminishing over time (Belland et al., 2017). Intersubjectivity is teachers' expectation that students will realize possible solutions and increase their personal responsibilities for solving the problem (Wood et al., 1976). The transferring of responsibility is students completing the target task without help (Belland et al., 2017).

Technology can also help provide scaffolding. While such technology-based scaffolding (TBS) lacks the dynamic adjustments and learning negotiation found in face-to-face scaffolding (Sharma & Hannafin, 2007), it may provide some routine support tasks and provide dynamic support for teachers scaffolding a whole class simultaneously. TBS may also help students engage the content and recognize alternative perspectives (Saye & Brush, 2002). A TBS approach is also an effective way to support students in large-sized classrooms (Belland, 2017), where teachers may not have enough time to individualize support. Previous studies on the use of scaffolding in STEM education have claimed that student learning improved (e.g., Belland et al., 2015; Belland et al., 2017; Kim et al., 2018).

Context and Purpose of the Study

For this study, the OHS implementation and data collection occurred across two high school physics courses at the same Midwestern rural high school. Participants included one physics teacher, who was also the designer of the system, and 39 junior and senior high school students. Ages ranged from 16 to 18 years old across 18 female students, 20 male students, and one student who did not respond to the question. The OHS was utilized for approximately one week prior to summative assessments on two specific units.

The problems addressed by this project were both practical and logistical. The practical problem was that a single physics teacher tasked with helping their students develop both their STEM learning and problem-solving abilities, had limited time and resources. The course textbook had a limited number of examples to share, so the teacher either had to recycle older examples or create new instances in their "free" time. The logistical problem was three-fold under the traditional homework method. The more time the teacher spent developing additional materials, the less time they had to dynamically scaffold their students' learning. Students relied on the teachers' supply of problems and feedback, repeating the cycle each time they needed additional support. Lastly, there was limited tracking available with the traditional homework. Absent self-reporting from students, the teacher had no way to know which steps or problems took the most time to solve, which types of questions students struggled with the most, and thus where to best focus their dynamic scaffolding.

Methods

To document how and why the OHS was developed in the way it was, as well as examining student reactions to it, we present the following case study. This study brings together teacher and students' reactions, leverages the practical nature of DBR, and makes use of both quantitative and qualitative data analyses. The use of the OHS serves as the bounding nature of the case, considering both the teacher/designer (the intent and the design) and the students (reaction to the design and use) as the main foci of the case.

Instruments

One semi-structured interview protocol was utilized for the teacher/designer, and one anonymous, online questionnaire was utilized for student participants. The interview protocol included ten questions about traditional homework methods, designing the OHS, and the teacher/designer's perception of the system.

The questionnaire consisted of a four-point Likert-type scale and four open-ended questions to measure student acceptance of the homework system. All closed-ended items were adopted from a previous study examining a Moodle system in a blended learning environment (see Yeou, 2016) and developed based on the technology acceptance model (TAM), including perceived usefulness (PU), perceived ease of use (PEU), computer self-efficacy (CSE), and attitude (A). TAM defines the factors affecting people's use of information technologies and helps researchers discover the impact of external factors on internal beliefs, attitudes, and intentions (Davis et al., 1989; Durodolu, 2016). Based on the TAM, if users have higher acceptance of a new system, they would be more likely to make an effort to use the system (Jones et al., 2010; Yeou, 2016). However, in this study, a four-point scale was adopted, with the neutral response removed to have participants take a position. Our modified scale maintained a high level of internal consistency, with A (α = .85), CSE (α = .75), PEU (α =.88), and PU (α =.91). Four open-ended questions were used to better understand the students' experiences and reactions to the system.

Data Collection and Analysis

The first and second authors (henceforth A1 and A2) were familiar with the teacher/designer's (A3) development of the OHS, having asked questions about it and providing feedback in earlier stages. It was decided that A1 and A2 would examine the entire design, system, and reaction to it to inform the next iteration of its design. Because of the team's familiarity with itself and the system, and A3's role as teacher to the student participants, steps were taken to limit potential bias. As a result, only A1 and A2 had access to the collected data and both coded the data, reaching agreement through discussion.

The teacher/designer interview was completed first to help inform the design of the open-ended survey questions and provide a context of intention to help interpret student reactions. After the interview was transcribed, a constant comparative approach (Merriam, 2009) was used to analyze it. After a process of open coding, we created categories and then themes. The questionnaire's open-ended questions were also analyzed using the same constant comparative approach. Descriptive statistics and correlation were used to analyze closed-ended questions. A total of 38 student responses were analyzed; one student's responses were discarded due to limited responses.

Findings

The Teacher, The Impetus, and the System

The teacher shared that the impetus for designing the system was mainly a consideration of time. This consisted of time in the form of how much he was using to go through each step of the homework problems, providing feedback, and creating new practice problems for students to complete. An online system would be able to provide immediate feedback, which would free up the teacher to provide more general and specific scaffolding as needed. An online system would also allow students to practice as much as they would like to fully develop their comfort and understanding. The system records would also allow the teacher to review student progress.

Scaffolding Theory and the Design of the System

The reviewed iteration of the system was designed to precede a summative assessment by approximately one week for each content section. The assessments were used to (a) identify the students' abilities in particular skills, (b) identify and understand what the problem is asking for, (c) identify all variables given, (d) identify what equation(s) will be used to solve the problem, (e) correctly solve the problem using mathematics, and (f) provide the answer with the correct units and significant figures. The system produces problems with randomly generated variables for each student, allowing them to solve the same problems many times. The teacher expected students to use the system with each unit for a week at school or home.

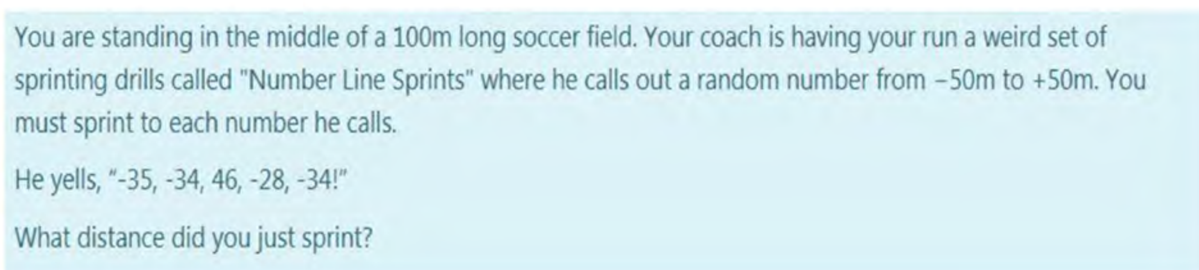
Each section was broken down into its chapter components as was taught during the rest of the course, specifically (1) Dimensional Motion and (2) Dimensional Motion, Forces, Momentum, and Energy. Regular paper-based homework in the classes studied consists of a single set of practice problems, with the students having access to a full answer key with problems worked out. The OHS's practice problems are identical, except for the randomly generated variables.

Constructing Problems

It is important to see examples of problems and how they are constructed. An example problem can be observed in Figure 1. The system was constructed using Moodle, a free and open-source learning management system (LMS), and facilitated via its free online hosting service Moodle Cloud (MC). By making use of MC, the system was already online and accessible by the teacher and students remotely instead of needing to worry about hosting the system locally and having to negotiate the school system's online security features. With MC already having basic settings and configurations in place, most of the teacher/designer's time and effort were focused solely on problem construction, variables, and hints.

For the problem presented in Figure 1, twenty sets of variables were created. Moodle uses the terminology of "wild cards" instead of variables, but their purpose is to provide multiple variations of a single problem by manipulating the numbers provided. An example of setting wild cards can be seen in Figure 2. Because the variables change for this and other problems, students can retry the same homework problem as many times as needed to feel confident in their ability and understanding. The example in Figure 1 is just one problem from one of the created practice sets that students would see; however, the problem variables are randomly generated from wild cards.

Figure 1. *An example of practice problems from the system*


You are standing in the middle of a 100m long soccer field. Your coach is having your run a weird set of sprinting drills called "Number Line Sprints" where he calls out a random number from −50m to +50m. You must sprint to each number he calls.

He yells, "-35, -34, 46, -28, -34!"

What distance did you just sprint?

Figure 2. *Variables to be used in problem construction*

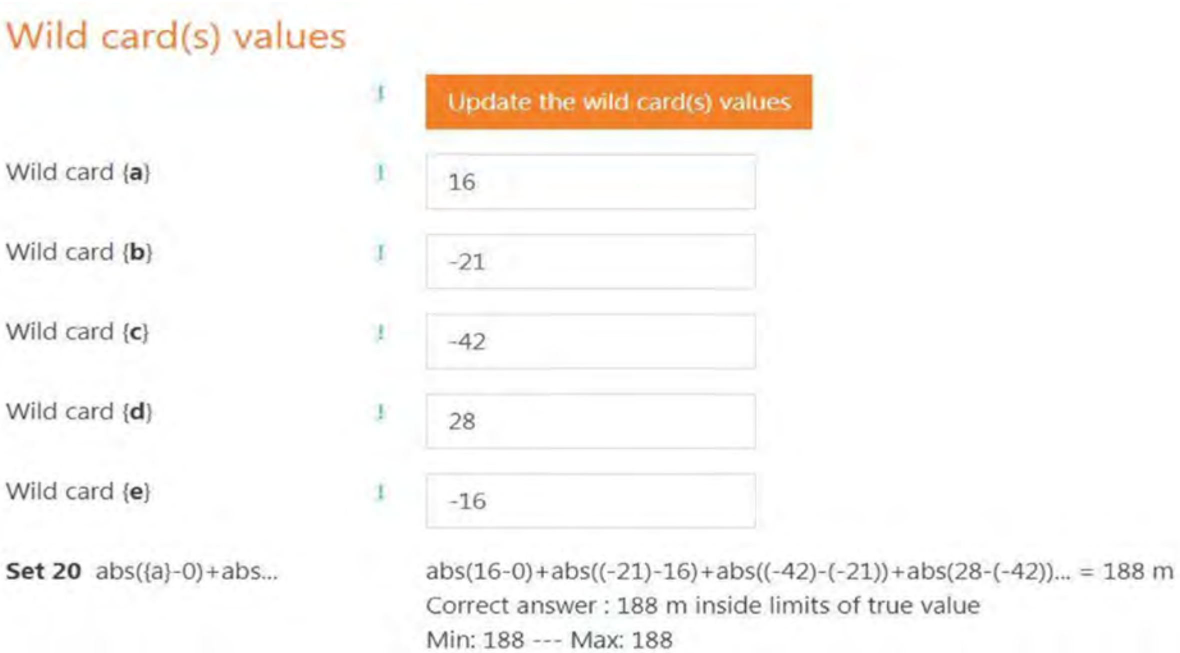


Figure 3. *Hints given after incorrect answers on the OHS*

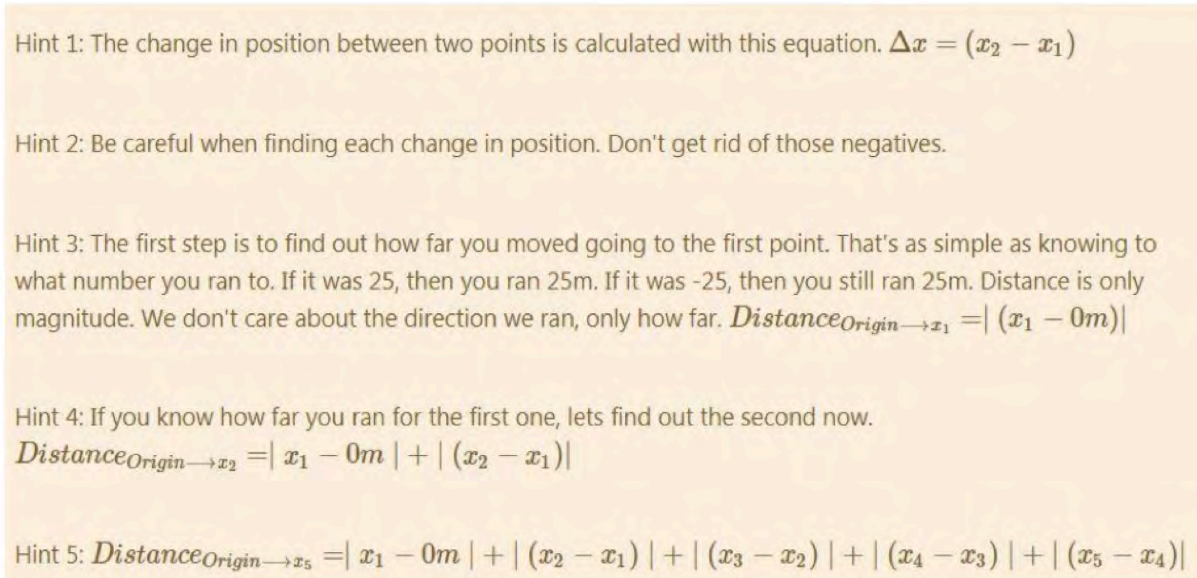
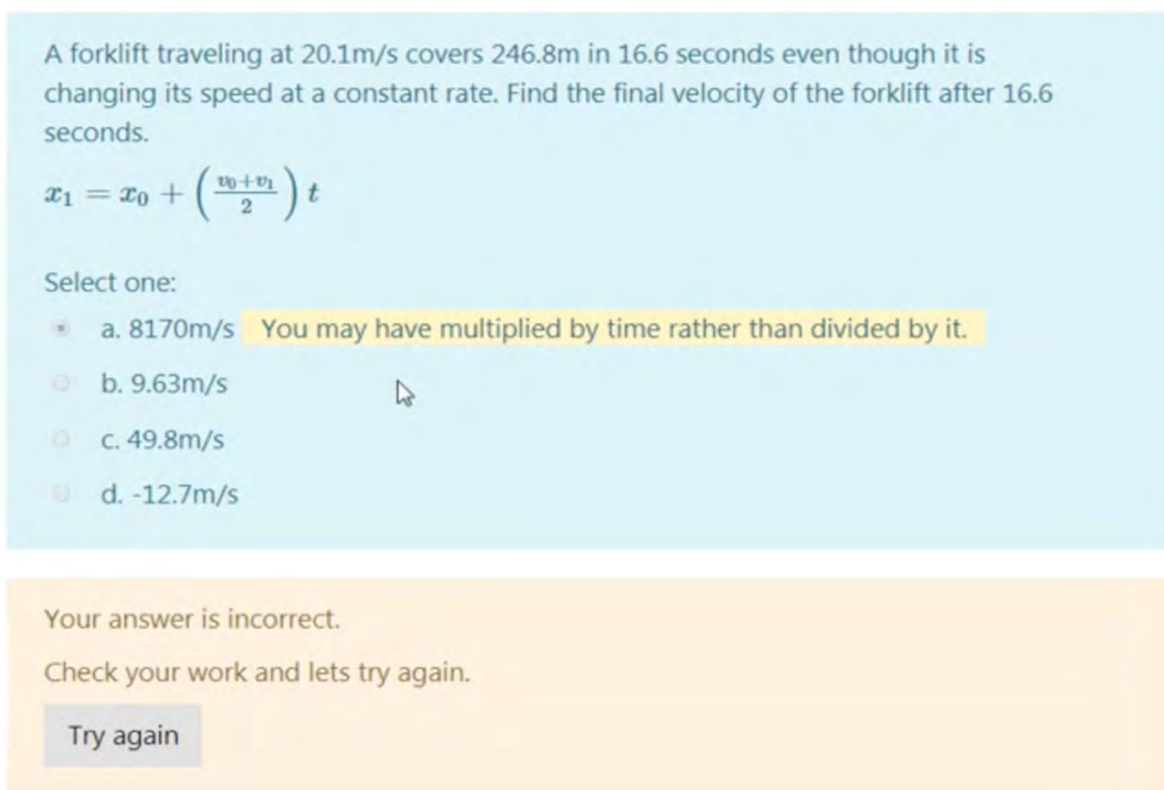


Figure 4. *An example of the specific corrective feedback*
Note: Students receive corrective feedback from an incorrectly answered multiple-choice question.



The teacher/designer created problems and also created a mathematical formula for the system to solve, given the variables generated (one example formula appears in Figure 2). Students never saw this formula, as it was not always a physics equation they would utilize, but rather a mathematical expression used for programming the problems appropriately. In addition to random variables, the problems provide opportunities for feedback to be prepared for wrong answers. In Moodle vernacular, these are identified as hints. Figure 3 demonstrates an example of feedback sequencing given after each incorrect answer to an open-ended problem. Figure 4 demonstrates an example of the feedback given for a multiple-choice question.

The teacher/designer also provided opportunities for students to be "close enough" to be correct through an acceptable error range. In Figure 5, the problem has an acceptable error range of 10%, so while the student is correctly within range, the system still shows the correct answer to further push students in their thinking, use of mental math, and risk-taking for approximation. Utilizing such feedback on practice problems embraces contingency scaffolding theory (Belland et al., 2017). The instructor attempts to increase the students' ability to learn through clues and modeling problem-solving practices. With the variable changes for the problems, students can retry the same homework problem as many times as needed to feel confident in their ability, which is the transfer of responsibility in scaffolding noted earlier.

During the process in which students attempt to solve the first problem, they recognize the possible answer to the problem, described as intersubjectivity in scaffolding theory (Belland et al., 2017). Each problem was set to allow five attempts to solve them with a minimum passing score of three points out of five, meaning that the students could submit a correct answer by their third attempt and still receive full credit for the problem. The teacher/designer decided this breakdown to promote student achievement instead of students fearing that each problem was a high-stake attempt, but also to limit random guessing. While a student may achieve a passing score after several attempts, if students needed or wanted to retry a problem, they could do so until they achieved a score they felt was acceptable.

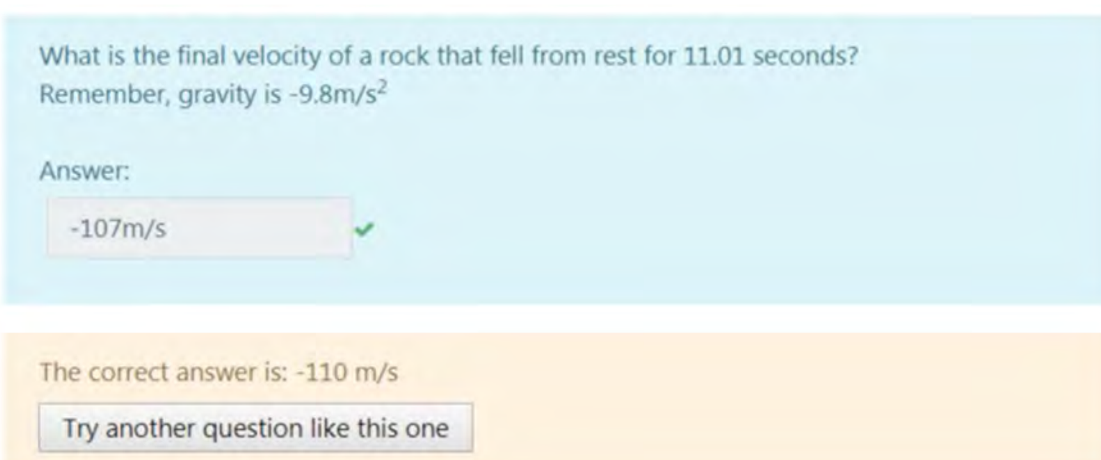
With this project, the use of variables and feedback/hints were intended to address several of these concerns. Giving different variables for the same questions reduces guessing behavior since students do not see the same limited number of questions. This variety, coupled with the hints, was intended to encourage students to try questions again and pursue additional ones. Allowing students to receive full credit, even if they require up to three attempts to solve each problem, was intended to promote students trying different problems and building up their understanding while limiting fear of failure.

An interview with the teacher and a survey of the students were carried out to reveal their reactions to the system and address the third guiding question. The interview data included challenges, problems, and how the teacher explained the impact of the system on students. Themes that emerged from the analysis included: System Problem-Solving, Growing Pains, and Positive Student Impacts.

The Process of Design and the Evaluation of the System from the Teacher Perspective

System Problem-Solving had to do with getting foundational elements of the system working. After deciding on Moodle as the system platform, the teacher/designer learned how to navigate and edit it to work

Figure 5. *An example of an open-ended response question*
Note: Open-ended questions accept answers within an acceptable error range



as he wanted and needed. One of the greatest efforts with this was learning all the details about developing physics questions using special figures within Moodle. The teacher also stated that technical limitations (i.e., how the special figures had to be entered and formatted), and the limited number of online resources he could locate addressing developing math and physics problems in Moodle, slowed the development of the system.

The next aspect of this System Problem-Solving theme had to do with creating feedback/hints, which involved considering when and what kind of feedback would appear, as well as meeting students' needs. When the students failed their first attempt, it should be related to their mistakes and help them solve the second attempt. This became a learning experience through trial and error, both for the teacher/designer and the students. The teacher created effective hints/feedback based on the specific class's actions and needs instead of generalizing. Even though he could not find official Moodle resources focused on creating and solving problems, other online resources helped him address his uncertainties.

The second emergent theme, Growing Pains, included challenges both the teacher and the students faced during the implementation of the system. The teacher/designer noted that adding students to the system was demanding for him during the implementation process. He also indicated that students had some confusion with both getting started with and learning to navigate the system because "Moodle is a full learning management system; there's a lot of options out there." The teacher/designer used only one of the system's features, solving problems, yet students had to navigate the entire Moodle site to reach the problems section. There can also be logistical problems for some students, especially those in a rural setting, as they still have to find internet access, log in to the system, and work through the problems on it.

Not all difficulties in using the system were related to technical matters, but instead affective ones. The teacher/designer claimed that some difficulties affecting students' use of the system were that some students do not like doing anything on computers, so they refused to use it. As a result of this, he had to print the questions out and prepare answer keys for those students who preferred a traditional homework approach. This issue eliminated the system's potential benefit to these students and added to the teacher/designer's workload. Another type of difficulty was a mix of technical and affective, based on how the system worked and how students would progress through it. The teacher/designer stated that the system forced students to "continue on the same problem until they exhaust their number of tries, they are given all of the hints, and then they are given a new problem with new numbers." This means that students have to work through the cycle each time for each problem, or as the teacher explains, "they either figure it out or ask for help." Although these cycles encourage the students to solve the problem or get help, some are not happy.

The final emergent theme, Positive Student Impacts, has to do with changes in behavior or students' understanding based on the system. The teacher indicated that because the system offers lower scores after each attempt, some students tended to devote their time to receiving a perfect score via repeating questions. This additional work reinforces their practice. Additional examples of positive student impacts were observed in the student reactions to the system.

Implementation and Students' Reaction to the System

Closed-ended Responses

Students' ratings on the questions focusing on perceived usefulness ($M = 1.93$, $SD = .55$) and perceived ease of use ($M = 1.96$, $SD = .59$) had moderate ratings, but PEU had a larger variance than PU, students' thoughts on whether using the homework system is easy. The mean of CSE ($M=1.88$, $SD=.58$) was lower than the other dimensions suggesting that the students were less convinced that they use the homework system without support. Although the students had moderate PU, PEU, and CSE scores, their attitude towards the OHS ($M=2.11$, $SD=.62$) were higher than in other dimensions.

A Pearson's product-moment correlation was run to assess the relationship among the PEU, PU, CSE, and A variables (see Table 1). There was a statistically significant, moderate positive correlation between perceived usefulness (PU) and perceived ease of use (PEU) $r(38) = .50$, $p< .05$, computer self-efficiency (CSE) and PEU $r(38) = .37$, $p< .05$, CSE and attitude (A) $r(38) = .50$, $p< .05$. PU had a higher correlation with CSE ($r(38) = .84$, $p< .05$) and A ($r(38) = .58$, $p< .05$). Attitude also had a significantly larger correlation with PEU ($r(38) = .64$, $p< .05$).

Open-ended Responses

Open-ended questions addressed student perceptions of the advantages, disadvantages, and most valuable aspects of the OHS; and if they would be willing to use such a system again. With each question effectively addressing its own category, the constant comparative analysis was limited to identifying instances where responses to questions may also address the other categories. Data were coded, and descriptive statistics for the students were calculated.

Advantages of the System. The majority of students ($n = 22/38$, 58%) thought the system's most significant advantage

Table 1. *Pearson Correlations for main study variables*			
	PEU	PU	CSE
PU	499*		
CSE	370*	837*	
A	637*	579*	499*
Note. *=statistically significant at p <.05 level			

was giving hints/feedback. While not indicating the hint/feedback system itself, some students highlighted the guidance provided by the system (n=13/38, 34%) and the instant nature of the feedback (n=5/38, 13%), both of which are aspects of the hint/feedback system. When students mentioned the hints, it appeared that they were referencing the hints provided with each of the open response-type questions (see Figure 3). When students spoke of the guidance provided, it appeared that they were focusing on the multiple-choice questions, where each incorrect solution gave a response as to what error they may have made to come up with that response (see Figure 4). Regardless, the hints/feedback helped students be successful, as one student shared that she could see what her "specific misunderstandings were in each problem. If I get the wrong answer, I'm not left to wonder what I don't understand or what I miscalculated but can get hints and hone-in on what my problems were" (Female Student 15).

The hint/feedback system also helped students feel less worried about being wrong instead of developing understanding. As one student shared, "The ability to submit your answer multiple times helps to lessen anxiety/frustration while working through problems" (Female student 11). This could help to create a positive mindset for students to improve, as one student shared, "The cool hints are helpful, and it is nice to get credit for understanding, not losing credit for not understanding" (Female Student 1). The hints/feedback could also be a source of knowledge reinforcement or reminders for students. One student indicated that "It gave me the help when I got questions wrong. It helped teach me when I forgot how to do the work" (Male Student 20). Another drew a comparison to his math class and not knowing where he had made mistakes with incorrect responses in that context (i.e., having traditional homework marked as incorrect only and no feedback provided).

Disadvantages of the System. Students had several concerns about the system, though it should be noted that 16% (n = 6/38) indicated that the system did not have disadvantages. A near majority of students (n = 18/38, 47%) reported technical concerns with the system's functioning, which were mostly (n=10/18) about the hint system, not addressing specific errors. As one student shared, "Often the hints that Moodle does give are not related to the mistake that was made and does not necessarily help" (Female student 39).

Other technical concerns were related to experiencing glitches (n=3/18) or initial challenges with registering for and entering the system (n=2/18) while some linked with the specificity of the system (like the hint/feedback comments above) was providing correct answers (n=3/10), but possibly not inputting them correctly. This can be a matter of simple formatting errors, though the teacher/designer noted in his interview that students would occasionally use incorrect units with their responses despite having everything else correct. One small vignette that appeared within the responses was of using the system versus interacting with the teacher. One student focused on the lack of interaction while another spoke about the quality of the interaction with the system being "Not quite as good as a 1 on 1 with a teacher" (Male student 25).

Most Valuable Aspect of the System and Using It Again. Almost two-thirds of the students (n=26/38, 68%) indicated that the hints/feedback were the most valuable. Of this group, nearly a third (n=8/26, 31%) emphasized procedural hints/feedback for how to solve problems as the most useful. While speaking to specific aspects of the hints/feedback, 16% (n=6/38) focused on their instant nature, and 13% (n=5/38) focused on the ability to either retry or redo problems. One student spoke to this, helping her move from understanding to application, she "liked that I could try the problem again and again until I understood and then could use those skills on the test" (Female student 15).

Students' willingness to use the online homework system. While two students did not answer this question, the majority of students (n=26/38, 68%) were willing to use the system or a similar system in the future. Three more students shared that they would be willing to use the system again if the hint/feedback issues noted in the disadvantages section could be resolved. However, eight students (21%) mentioned that they prefer traditional homework without indicating a specific reason.

Discussion

This DBR project used a case study design supported with both quantitative and qualitative data to examine the development and use of an OHS. It was developed for and used with two sections of a physics course to help promote STEM learning and problem-solving.

This project's findings supported past studies' findings that OHSs could be effective systems for giving teachers more time for other activities and provide instant feedback to students (e.g., Mendicino et al., 2009; Wood & Bhute, 2019), support students to make progress at their own pace, be accessible on-demand, and could provide automatic grading (Doorn et al., 2010; LaRose, 2010; Mendicino et al., 2009; Smolira, 2008).

The system was also intended to address some of the critiques of online systems noted in the literature (e.g., Fatemi et al., 2015; Kortemeyer, 2015). Critics posited findings such as multiple attempts not improving students' performance (Rhodes & Sarbaum, 2015), development of lower-level learning (Fish, 2015), and the development of rapid-guessing behavior (Mendicino et al., 2009; Wise, 2017). However, since this OHS offered multiple tries for students with different variables, it reinforces their practice not to guess the answer, which helps students get the highest score (Doorn et al., 2010). Further, hints were provided after each wrong answer so that students could reflect on the process they had used to improve their problem-solving skills. Students' ability to speed through questions was hampered by needing to review each hint or feedback before they could proceed, hopefully learning an important point about solving the problem before moving on to subsequent attempts. With students having the option not to use the system, there had to be a certain level of engagement already for them to be using it and thus be less likely to engage in rapid guessing.

As part of the project evaluation, the teacher/designer and students shared their experiences and reactions to the OHS. The teacher/designer faced several challenges during the development process: The technology used, the technological experiences he had, and online resources all influenced the design and implementation processes, which would reduce after the teacher learned the system. Moreover, teachers need to know their students' needs for their courses and what ways are effective in enhancing students' skills while designing such systems. Students' responses supported the assertion that the system should provide appropriate hints for students' needs, suggesting some possible disconnects between identified needs and that the system may not be able to dynamically adjust to how students are making errors in problem-solving. While some hints/feedback did not meet students' needs, more than half of the students liked getting hints and the guidance provided by the system. This could suggest that even if one hint might not help with the specific question at hand, it could still be a source of reflection and reinforcement for students in being able to solve other problems later.

The results of the survey indicated that while the students had moderate scores of PU, PEU, and CSE, their attitude towards the OHS was higher than in other dimensions. We interpret this result as the students liking the OHS, even though they had some concerns about the technology and the system. This issue was also observed in the qualitative data analysis, in which most students had positive reactions to feedback/hint features of the system and liked the OHS but voiced some concerns about technical issues. Furthermore, there were statistically significant relationships between variables, but the correlation between CSE and PEU was lower than others. These results suggested that all dimensions of TAM are related; however, improving students' skills or supporting students when they use the system might enhance their acceptance of a new system.

Finally, it was also not clear that students understood that the teacher was actively reviewing reports from the homework system to see where students were struggling, and which students might need additional assistance. It may be that this portion of the teachers' pedagogical approach may need to be made more transparent to the students, in that he could tell them he is using data from the system to help focus each class period and better inform remediation efforts. Such notes could also appear as scaffolding within the system in the form of introductory or concluding statements for each problem set which students work through.

Conclusion and Limitations

We found the OHS might be an effective solution to support students' problem solving in a physics course. The DBR approach is sufficiently adaptable to allow the collaborating practitioner to be the OHS designer and not just a more traditional partner to test a researcher-developed solution. We would encourage other DBR project teams to experiment with different collaborative configurations and report out their results, in addition to the outcomes of their designs.

Like all educational research studies, this study has some limitations. First, with DBR and a case study design, the findings and the discussion from this project may not generalize to other contexts. DBR, by its very nature, focuses on a specific design/context, much like how case studies focus on a uniquely bound phenomenon. However, it is hoped that the project details and findings are described in sufficient detail to allow for some amount of transferability to others researching, designing, or developing OHSs in K-12 schools or other educational settings. As noted by Brown (1992), because of the complexity of DBR projects, a great variety of data can be and are available, often being too much to work with. With this in mind, we focused on the development of the system and both the teacher/designer and student reactions to it. As a result, we will have missed out on other data analysis opportunities, but we intend to investigate more of these in upcoming design iterations. Further, the teacher/designer spent time on some technical difficulties when developing the system, which might discourage other teachers from using the OHS. However, such challenges are possible when teachers start to use new technologies and usually reduce after getting used to these systems. We hope that this project's reporting will help limit such discouragement for others developing OHSs and similar systems.

Finally, the sample was limited to one teacher and 38 high school students. Future research can expand this work to include larger samples of students and teachers to allow for more comprehensive findings. This might take the form of sampling physics classes across a great variety of schools or expanding the system to include other subject areas and grade levels to examine if teacher and student reactions vary based on subject area or grade level. Future research should also include how adaptive OHSs can become. The OHS in this study would sometimes provide feedback that was not relevant to the question the student was currently working on. We will need to further explore how much flexibility is present in the Moodle system that was used for the current iteration of the OHS. If it is insufficient, another open source platform such as Canvas or the Sakai Project will be examined until we find one that has the additional flexibility to be more adaptive in providing feedback to students and build a new iteration from that as the foundation.

The COVID-19 pandemic has provided an opportunity to re-think and re-examine educational technologies. Learning loss was a big problem during the pandemic (Hammerstein et al., 2021; Psacharopoulos et al., 2021). However, some studies (e.g., Angrist et al., 2020; Meeter, 2021; Spitzer & Musslick, 2021; van der Velde et al., 2021) have shown that using technologies in education mitigated the learning losses. Even though most K-12 schools have gone back to traditional teaching methods before the end of the pandemic, this experience helped teachers and students understand the use of educational technologies and their effects on teaching and learning. Teachers' experiences during the pandemic may encourage them to develop and use such OHSs that might provide a way for teachers to better assist students as they remain in hybrid environments and/or transition back to the face-to-face classroom, while also freeing themselves up for more dynamic scaffolding and instruction.

In thinking beyond COVID and on to the next pandemic, or other extended time away from school, the development of such an OHS might also provide an alternative to the so-called blizzard bags or other take home print packets that some schools used at the start of the pandemic. Some of these schools found the bags and packets to be lacking when the limited amount of work did not match the growing time that students ended up being out of school (e.g. Giunco et al, 2020). An OHS like the one described in this study does not run out of workable problems, so certain modules could run indefinitely while other new content is developed. While it may not be the system examined in this study, such systems may change the way students interact with take home or make-up work in the future, even beyond extended absences from school. The current study is a good resource to understand students' reactions to these types of systems and minimize possible challenges when developing systems in the future.

References

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research? *Educational Researcher*, *41*(1), 16-25. https://doi.org/10.3102%2F0013189X11428813

Angrist, N., Bergman, P., Brewster, C., & Matsheng, M. (2020). Stemming learning loss during the pandemic: A rapid randomized trial of a low-tech intervention in Botswana. *Available at SSRN 3663098*. https://dx.doi.org/10.2139/ssrn.3663098

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences*, *13*(1), 1-14. https://doi.org/10.1207/s15327809jls1301_1

Bas, G., Senturk, C., & Cigerci, F. M. (2017). Homework and academic achievement: A meta-analytic review of research. *Issues in Educational Research*, *27*(1), 31. http://www.iier.org.au/iier27/bas.html

Bausell, C. V., & Klemick, E. (2008). Tracking U.S. trends. *Education week: Technology counts*, *27*(30), 39–42. http://t.edtechpolicy.org/AAASGW/Session3/Education%20Week_%20Tracking%20U.S.pdf

Belland, B. R. (2017). *Instructional scaffolding in STEM education*. Springer International.

Belland, B. R., Walker, A. E., Kim, N. J., & Lefler, M. (2017). Synthesizing results from empirical research on computer-based scaffolding in STEM education: A meta-analysis. *Review of Educational Research*, *87*(2), 309-344. https://doi.org/10.3102%2F0034654316670999

Belland, B. R., Walker, A. E., Olsen, M. W., & Leary, H. (2015). A pilot meta-analysis of computer-based scaffolding in STEM education. *Educational Technology & Society*, *18*(1), 183–197. https://www.jstor.org/stable/jeductechsoci.18.1.183

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning*

Sciences, *2*(2), 141–178. https://doi.org/10.1207/s15327809jls0202_2

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management science, 35*(8), 982-1003. https://doi.org/10.1287/mnsc.35.8.982

Doorn, D. J., Janssen, S., & O'Brien, M. (2010). Student attitudes and approaches to online homework. *International Journal for the Scholarship of Teaching and Learning, 4*(1), 1-20. https://files.eric.ed.gov/fulltext/EJ1136138.pdf

Durodolu, O. O. (2016). Technology acceptance model as a predictor of using information system' to acquire information literacy skills. *Library Philosophy and Practice* (e-journal). Retrieved from http://digitalcommons.unl.edu/libphilprac/1450

Fatemi, D. J., Marquis, L., & Wasan, S. (2015). Student performance in intermediate accounting: A comparison of the effectiveness of online and manual homework assignments. *The Accounting Educators' Journal*, *24*, 1-19. http://aejournal.com/ojs/index.php/aej/article/view/259/138

Fish, L. A. (2015). Undergraduate students' computer-managed homework versus in-class performance for different testing formats. *Business Education Innovation Journal, 7*, 5-14. http://www.beijournal.com/images/V7N2_final.pdf

Gibbs, B. (2014). Reconfiguring Bruner: Compressing the spiral curriculum. *Phi Delta Kappa*, 95(7), 41–44. https://doi.org/10.1177/003172171409500710

Giunco, K. M., Rosen-Reynoso, M., Friedman, A. A., Hunter, C. J., & Cownie III, C. T. (2020). Lessons from the field: Catholic school educators and COVID-19. *Journal of Catholic Education*, *23*(1), 243-267.

Gray, L., Thomas, N., & Lewis, L. (2010). *Teachers' use of educational technology in U.S. public schools: 2009* (NCES 2010-040). National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. Washington, DC. https://nces.ed.gov/pubs2010/2010040.pdf

Hammerstein, S., König, C., Dreisörner, T., & Frey, A. (2021). Effects of COVID-19-related school closures on student achievement-a systematic review. *Frontiers in Psychology*, 4020. https://doi.org/10.3389/fpsyg.2021.746289

International Society for Technology in Education. (2000). *National educational technology standards for students: Connecting curriculum and technology*. Eugene, OR.

International Society for Technology in Education. (2002). *National educational technology standards for teachers: Preparing teachers to use technology*. Eugene, OR.

International Society for Technology in Education (2016a). *ISTE standards for students*. https://www.iste.org/standards/for-students.

International Society for Technology in Education (2016b). *ISTE standards for educators.* https://www.iste.org/standards/for-educators.

International Society for Technology in Education. (2018, October). *ISTE announces new computational thinking standards for all educators.* https://www.iste.org/explore/Press-Releases/ISTE-Announces-New-Computational-Thinking-Standards-for-All-Educators

Jones, C. M., McCarthy, R. V., & Halawi, L. (2010). Utilizing the technology acceptance model to assess the employee adoption of information systems security measures. *Journal of International Technology and Information Management,* 11(1). https://commons.erau.edu/publication/310

Kim, N. J., Belland, B. R., & Walker, A. E. (2018). Effectiveness of computer-based scaffolding in the context of problem-based learning for STEM education: Bayesian meta-analysis. *Educational Psychology Review, 30*(2), 397-429. https://psycnet.apa.org/doi/10.1007/s10648-017-9419-1

Kortemeyer, G. (2015). An empirical study of the effect of granting multiple tries for online homework. *American Journal of Physics*, *83*(7), 646-653. https://doi.org/10.1119/1.4922256

Larkin, J., & Chabay, R. (1992). *Intelligent tutoring systems and computer assisted instruction: shared issues and complementary approaches*. Erlabaum.

LaRose, P. G. (2010). The impact of implementing web homework in second-semester calculus. *Primus: Problems, resources, and issues in mathematics undergraduate studies, 20*(8), 664-683. https://doi.org/10.1080/10511970902839039

Lenz, L. (2010). The effect of a web-based homework system on student outcomes in a first-year mathematics course. *Journal of Computers in Mathematics and Science Teaching,* *29*(3), 233-246. https://www.learntechlib.org/primary/p/32318/

Meeter, M. (2021). Primary school mathematics during the COVID-19 pandemic: No evidence of learning gaps in adaptive practicing results. *Trends in neuroscience and education*, 25,100163. https://doi.org/10.1016/j.tine.2021.100163

Mendicino, M., Razzaq, L., & Heffernan, N. T. (2009). A comparison of traditional homework to computer-supported homework. *Journal of Research on Technology in Education*, *41*(3), 331-359. https://files.eric.ed.gov/fulltext/EJ835243.pdf

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. John Wiley & Sons, Incorporated.

Pellegrino, J., Goldman, S., Bertenthal, M., & Lawless, K. (2007). Teacher education and technology: initial results from the "what works and why" project. *Yearbook of the National Society for the Study of Education, 106*(2), 52–86. https://doi.org/10.1111/j.1744-7984.2007.00115.x

Psacharopoulos, G., Collis, V., Patrinos, H. A., & Vegas, E. (2021). The COVID-19 cost of school closures in earnings and income across the world. *Comparative Education Review, 65*(2), 271-287. https://www.journals.uchicago.edu/doi/abs/10.1086/713540

Rhodes, M. T., & Sarbaum, J. K. (2015). Online homework management systems: Should we allow multiple attempts? *The American Economist*, *60*(2), 120-131. https://doi.org/10.1177%2F056943451506000203

Saye, J. W., & Brush, T. (2002). Scaffolding critical reasoning about history and social issues in multimedia-supported learning environments. *Educational Technology Research and Development*, *50*(3), 77-96. https://doi.org/10.1007/BF02505026

Sharma, P., & Hannafin, M. J. (2007). Scaffolding in technology-enhanced learning environments. *Interactive learning environments*, *15*(1), 27-46. https://doi.org/10.1080/10494820600996972

Smolinsky, L., Olafsson, G., Marx, B. D., & Wang, G. (2019). Online and handwritten homework in calculus for STEM majors. *Journal of Educational Computing Research, 57*(6), 1513–1533. https://doi.org/10.1177%2F0735633118800808

Smolira, J. C. (2008). Student perceptions of online homework in introductory finance courses. *Journal of Education for Business, 84*(2), 90-95. https://www.learntechlib.org/p/74616/

Spitzer, M. W. H., & Musslick, S. (2021). Academic performance of k-12 students in an online-learning environment for mathematics increased during the shutdown of schools in wake of the COVID-19 pandemic. *PloS one, 16*(8), e0255629. https://doi.org/10.1371/journal.pone.0255629

UNESCO. (2020). Education: From disruption to recovery. School closures caused by Coronavirus (Covid-19). Retrieved from https://en.unesco.org/covid19/educationresponse

U.S. Department of Education, Office of Educational Technology. (2016). *Future ready learning: Reimagining the role of technology in education*. Washington, D.C. https://tech.ed.gov/files/2015/12/NETP16.pdf

U.S. Department of Education, Office of Educational Technology (2017). *Reimagining the role of technology in education: 2017 national education technology plan Update,* Washington, D.C. https://tech.ed.gov/files/2017/01/NETP17.pdf

U.S. Department of Education, Office of Educational Technology. (2019, October). *Innovation spotlights: Nine dimensions for supporting powerful STEM learning with technology.* https://tech.ed.gov/files/2019/10/stem-innovation-spotlights-research-synthesis.pdf

van der Velde, M., Sense, F., Spijkers, R., Meeter, M., and van Rijn, H. (2021). Lockdown learning: changes in online study activity and performance of Dutch secondary school students during the COVID-19 pandemic. *PsyArXiv*. https://doi.org/10.3389/feduc.2021.712987

West, A., Swanson, J., & Lipscomb, L. (2019). Scaffolding. In P. Lombardi (Ed.), *Instructional methods, strategies and technologies to meet the needs of all learners*. https://granite.pressbooks.pub/teachingdiverselearners/

White House Office of Science and Technology Policy (2018). *Charting a Course for Success: America's Strategy for STEM Education. A Report by the Committee on STEM Education of the National Science & Technology Council.* https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf

Wise, S. L. (2017). Rapid-guessing behavior: Its identification, interpretation, and implications. *Educational Measurement: Issues and Practice*, *36*(4), 52-61. https://doi.org/10.1111/emip.12165

Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*(2), 89-100. https://doi.org/10.1111/j.1469-7610.1976.tb00381.x

Wood, P. M., & Bhute, V. (2019). Exploring student perception toward online homework and comparison with paper homework in an introductory probability course. *Journal of College Science Teaching, 48*(5), 68-75. https://eric.ed.gov/?id=EJ1215797

Yeou, M. (2016). An investigation of students' acceptance of Moodle in a blended learning setting using technology acceptance model. *Journal of Educational Technology Systems, 44*(3), 300-318. https://doi.org/10.1177%2F0047239515618464

Zerr, R. (2007). A quantitative and qualitative analysis of the effectiveness of online homework in first-semester calculus. *The Journal of Computers in Mathematics and Science Teaching, 26*(1), 55-73. https://eric.ed.gov/?id=EJ752320