An initial exploration of teacher integration of interactive technology in statistics education

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Our study explored how secondary mathematics teachers integrate the DOTS applet, a digital tool designed to support distributional reasoning, into statistics tasks. Three pre-service and in-service teachers participated in a retrospective qualitative case study, where they created and reflected on tasks that integrated the applet. Qualitative content analysis of the teachers' written submissions focused on technology integration and the development of distributional reasoning. Results revealed both similarities, such as promoting interactive engagement, and differences, including the use of context, conceptual focus, and the balance between exploration and guidance. These findings highlight that the same technology can be used in diverse ways to support student learning, emphasizing the importance of intentional task design aligned with specific learning objectives. This research contributes to STEAM education by providing indications of how teachers' pedagogical intentions shape the integration of technology in statistics education.

INTRODUCTION

Advances in technology have the potential to support statistical meaning-making by providing multiple representations of statistical content and opportunities for students' active engagement (Dick & Hollebrands, 2011). One such technology is the DOTS applet (Fergusson, 2017), which was designed specifically to support the development of distributional reasoning by providing an interactive environment where cornerstone concepts in descriptive statistics such as mean and standard deviation can be explored. There are many models in STEAM education literature framing different types of technology integration (Goos et al., 2000; Misha & Koehler, 2006; Pea, 1985; Puentedura, 2020), but limited research exploring the utility of these models specifically for designing statistics and data science tasks (e.g., Lovett & Lee, 2017). In this paper, we carried out an initial exploration of teachers' plans to integrate the DOTS applet into a statistics task to investigate the viability and potential research benefits of a larger scale study in the future.

BACKGROUND

There are a variety of technologies available for teaching statistics and a variety of ways in which these technologies could be used. Examples of tools used for teaching statistics include statistical software packages, graphics calculators, spreadsheets, programming languages, "microworlds" or custom-built applications, interactive tutorials or books, and interactive documents such as notebooks (cf. Ben-Zvi, 2000; Biehler, 1997a). Statistics education researchers have given considerable attention to how computational tools shape students' statistical thinking, as well as to the complex interplay between software features, task design, and learners' statistical conceptions (e.g., Ben-Zvi, 2000; Biehler, 1997b; delMas, 1997). It is essential that computational tools are used to support the development of statistical concepts (Chance & Rossman, 2006), with careful thought given to how students build both conceptual and tool-based understanding in tandem (cf. instrumental genesis, Artigue, 2002), and to the dynamic relationship between tool, task, and student thinking (Biehler, 2018; Doerr & Pratt, 2008; Moore, 1997).

Within mathematics education research, Dick & Hollebrands (2011) define mathematical action technologies as platforms which allow students to act on mathematical objects and create meaning for themselves. Even though they do not use the term "mathematical action" technologies, Zbiek et al. (2007) provided a detailed synthesis for the place of cognitive tools for mathematical activity highlighting the importance of user actions on mathematical objects (or their representations) and the feedback that tool provides. They stated that "identifying students' types of activity and behaviors when using technological tools is important, and from a research standpoint it is desirable to use the type of activity in which they engage (exploratory and expressive) and their corresponding behaviors…to infer what students are thinking" (p. 1187). Hollebrands and Lovett (2016) highlighted that technology allows

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these by “opening opportunities for students to engage in mathematical sense making and reasoning or eliciting evidence of students’ mathematical thinking” (p. 1).

The interplay between technology and pedagogy and how teachers engage students using technology can significantly shape students' mathematical and statistical behaviors. Zbiek et al. (2007) highlight that "students’ mathematical behaviors [using a cognitive tool within a technological environment] is, of course, greatly influenced by the ways teachers choose to engage them in mathematical activity" (p. 1187). The strategic and intentional incorporation of technology by teachers could create effective teaching environments for statistics learning. Hollebrands and Lovett (2016) assert that "technology can provide teachers with unique opportunities to create engaging and thought provoking mathematical tasks and questions. Thus, the power of technology in the teaching and learning of statistics is not necessarily in the answers technology provides but in the questions and tasks it allows teachers and students to ask" (p. 2). This speaks to the power of teaching methodologies and technological tools fostering a deeper understanding of statistical concepts and promoting active learning among students. Hershkowitz et al. (2002) stated that “statistics learning is a particularly powerful testing ground for probing fundamental questions regarding the role of computerized environments in curriculum development” (p. 690).

Teachers are the ones who select and integrate various technologies into their lessons. Given the complexity of teacher knowledge, Mishra and Koehler’s (2006) Technological Pedagogical and Content Knowledge (TPACK) model illustrates how multiple dimensions of teacher knowledge interact when technology is integrated in instruction. Building on this framework, Lovett and Lee (2017) interpreted the TPACK model specifically to the context of teaching statistics with preservice mathematics teachers. Education literature offers numerous frameworks for understanding how technology can be integrated into teaching. For instance, Pea (1985) introduced two metaphors for technology use—amplifier and reorganizer—while Goos et al. (2000) identified four roles technology can play in the classroom: *Master, Servant, Partner*, and *Extension-of-self*. Similarly, Puentedura’s (2020) SAMR model outlines four progressing levels of technology integration: *Substitution, Augmentation, Modification,* and *Redefinition*.

The SAMR model offers a practical framework for evaluating and guiding technology integration in the classroom. At the *Substitution* level, technology acts as a direct replacement for traditional tools, with no functional change. *Augmentation* adds functional improvements. *Modification* allows for significant task redesign. At the highest level, *Redefinition* involves the creation of new, previously inconceivable learning tasks and experiences due to the use of technology. While both frameworks are broadly applicable across disciplines, TPACK provides a holistic perspective by emphasizing the interplay between content, pedagogy, and technology in effective teaching with special focus on teacher knowledge. SAMR, on the other hand, focuses more on evaluating and guiding the depth of technology integration in student tasks, offering a practical hierarchy that helps educators reflect on how technology might transform learning experiences.

One area for considering the use of technological tools for developing conceptual understanding are the fundamental concepts of the mean and standard deviation, as these are both concepts that can be difficult for students to grasp (e.g., McGatha et al, 2002; Pollatsek et al., 1981). For instance, delMas & Liu (2005) explored how introductory statistics students developed understanding of standard deviation as they interacted with a purpose-built computational environment, guided by an interviewer. Within this computational environment, students were able to interact with the data by moving the bars of a graph around on the computer screen, where the bars represented the frequencies of different outcomes within a data set. Over a series of phases, different types of student interaction with the data distribution were enacted, leading to different observations of student thinking and reasoning about mean and standard deviation. The use of technology supported statistical meaning-making by providing interactive representations of statistics content and opportunities for students’ active engagement, including one-on-one interactions with the data inside the technology.

There is a lack of research on how teachers design statistical tasks with technology which considers the different intentions or motivations for task design decisions. As Arnold et al. (2018) observed, both teachers and researchers tend to rely on implicit design principles when creating learning activities. In statistics education and the emerging field of data science education, researchers infrequently provide detailed descriptions of the tasks they use or discuss how particular task design features affect learning, a situation that is also found in mathematics education (Watson & Ohtani, 2015). Hence, our research question for this study was: *What technological features and pedagogical intentions appear to guide the teachers' task design decisions when integrating the DOTS applet into a statistics task?*

THE TECHNOLOGICAL DESIGN OF THE DOTS APPLET

The DOTS applet was developed to help students estimate the mean and standard deviation of a discrete random variable using visual and interactive features of a dot plot. The applet was developed by the second author (Fergusson, 2017) and is available at learning.statistics-is-awesome.org/dots/. The tool was created in response to the need for students to develop an intuitive and conceptual understanding of these properties, rather than relying solely on mathematical formulas. Existing tools at the time did not allow students to drag dots and instantly observe changes to the mean and standard deviation while maintaining a focus on these features. The DOTS applet enables users to construct dot plots by dragging dots onto a plot or by importing data directly via a URL. For example, students can visualize the ages of cats from a dataset, estimate the mean by clicking below the axis, and then use built-in features to reveal the actual mean, or test their estimate using the "Balance test" (Figure 1).

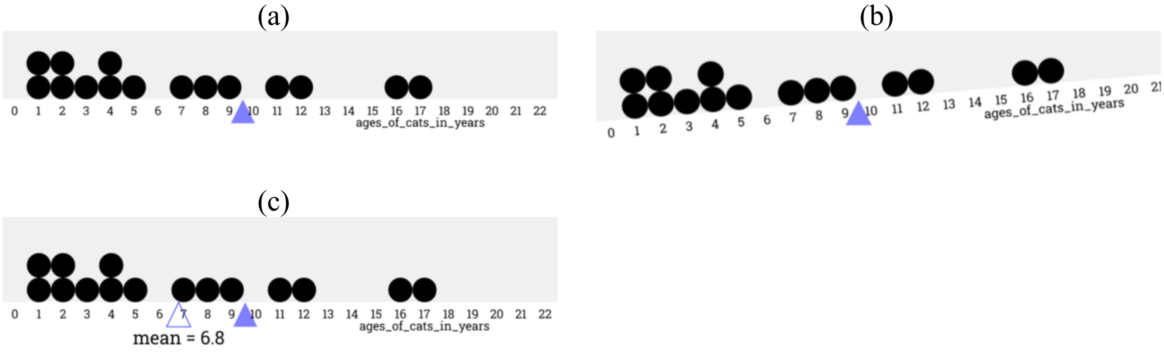


Figure 1. Screenshots from the DOTS applet showing (a) an estimate of the mean using a filled purple triangle, (b) the balance test using this estimate, and (c) the estimated mean and the actual mean.

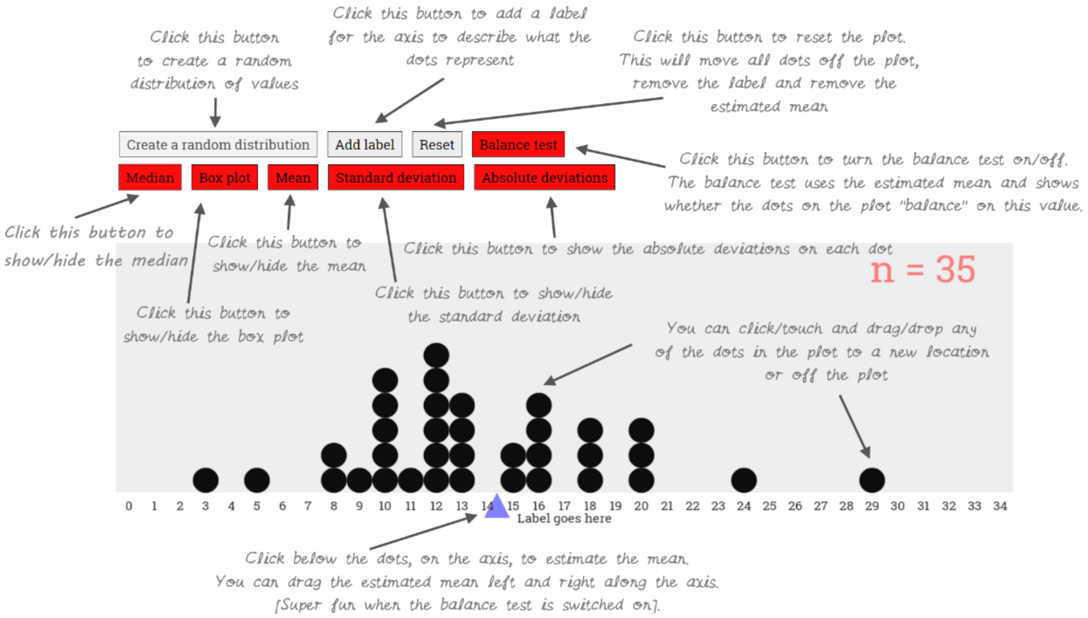
The design of the DOTS applet is intended to reinforce an approach that conceives of the mean as a balancing point. For standard deviation, the applet encourages students to visualize it as the average distance of each dot from the mean by exploring absolute deviations. A key feature of the applet is the "random distribution" option, which allows students to experiment with distributions and observe the effects of changes on the mean and standard deviation.

RESEARCH APPROACH

In this study, we studied how teachers integrated the DOTS applet into a statistics task. We conducted a retrospective qualitative case study involving three secondary school mathematics teachers. The Wayne State University *Human Participant Research Determination Tool* was used for this project, resulting in a determination that IRB oversight was not required. This exploratory study was designed to assess the viability and potential research benefits of carrying out a similar study on a much larger scale involving secondary school mathematics and statistics teachers in both the US and New Zealand. Hence, the focus of our research for this study was to determine whether the teachers' written submissions about how they planned to integrate the DOTS applet into a statistics task would provide rich and meaningful data for analysis.

The participants were pre-and in-service teachers who were taking a graduate level course at Wayne State University (US) to study teaching and learning of statistics and probability for K-12 grades. The course was designed for master's students who are certified teachers and graduate students who have a bachelor's degree already and would like to become a teacher. In the term that this study was conducted there were three students taking the course, one certified high school teacher and two pre-service teachers who are seeking certification for grades 6-12. The course was a hybrid course including synchronous and asynchronous portions and included readings from premier research journals on K-12 teaching and learning of statistics and probability.

The teachers were asked to explore the DOTS applet and then create a task using the applet. The teachers had not previously used the DOTS applet and were given a diagram which provided annotations on a screenshot of the applet, explaining the different buttons (Figure 2).



Click this button to create a random distribution of values

Click this button to add a label for the axis to describe what the dots represent

Click this button to reset the plot. This will move all dots off the plot, remove the label and remove the estimated mean

Click this button to turn the balance test on/off. The balance test uses the estimated mean and shows whether the dots on the plot "balance" on this value.

Click this button to show/hide the median

Click this button to show/hide the mean

Click this button to show the absolute deviations on each dot

Click this button to show/hide the box plot

Click this button to show/hide the standard deviation

You can click/touch and drag/drop any of the dots in the plot to a new location or off the plot

Click below the dots, on the axis, to estimate the mean. You can drag the estimated mean left and right along the axis. [Super fun when the balance test is switched on].

Figure 2. The annotated screenshot of the DOTS applet provided to the teacher participants.

For the design of their task, they were asked to write: (1) the main aim of their task; (2) the description of the task, listing its structure and main questions; (3) how the task used the DOTS applet; (4) how the task might support student thinking and understanding; (5) potential affordances and limitations of using the DOTS applet; and (6) how they would implement this task in the classroom and what would be the role of DOTS applet. After submitting their own task, the teachers were asked to comment on the tasks designed by other teachers and to respond to additional questions posed by the course instructor (first author) to clarify their design intentions. We expected that the teachers would describe tasks that focused on interactivity, given the dynamic nature of the DOTS applet, but we were unsure about how they would design for student engagement.

The data used for this study includes all the teachers' written submissions: the task descriptions for using DOTS applet, their reflections on the applet itself, and their responses to additional questions. To identify what technological features and pedagogical intentions appeared to guide the teachers' task design decisions, we conducted a qualitative content analysis of their written submissions. We collated the three teacher submissions into a single table, with one column per teacher, and then read within and across the task descriptions, reflections, and responses, paying special attention to the teachers' considerations of integrating technology to support development of distributional reasoning concepts. We then developed a coding framework based on key features of effective statistical tasks involving technology (e.g., Bargagliotti & Franklin, 2015; Ben-Zvi, 2000; Biehler, 2018), the pedagogical goals evident in the tasks, and the specific affordances of the DOTS applet. We used a process of constant comparison (e.g., Bakker & Van Eerde, 2015) to iteratively refine the key categories of our coding framework, and to provide descriptions of codes that could be used within each category to characterize the teachers' task design intentions.

Additionally, we applied the SAMR model (Puentedura, 2020) to classify the integration of the DOTS applet for each task as *Substitution, Augmentation, Modification,* or *Redefinition*. If the DOTS applet was used to replace a traditional approach, such as drawing a data distribution by hand, we coded it as *Substitution*. If the task contained features like interactive visualization that improved the task but did not alter its core focus on calculations of central tendency, we coded it as *Augmentation*. If the teacher described a task that centered visual interactive experiences with distributional reasoning, we coded it as *Modification*. If the teacher described an entirely new inquiry-based learning experience only made possible by the applet, we coded it as *Redefinition*.

RESULTS

Our qualitative content analysis of the teachers' written submissions indicates that the implementation of the activity provided rich and meaningful data about their task design decisions. All the tasks developed by the teachers took advantage of the interactive nature of the DOTS applet, as expected, and in general teachers' pedagogical intentions appeared to be that students would use this technology to either investigate or discover statistical concepts. Table 1 provides an overview of how the tasks were classified based on the SAMR model.

Table 1. SAMR model-based classifications for the integration of the DOTS applet for each task.

Task 1	Augmentation	Used DOTS to provide interactive and visual representations of statistical concepts, but did not fundamentally change how the task would have been designed without technology
Task 2	Modification	Used DOTS to encourage students to explore and investigate statistical concepts in a more interactive and dynamic way, including use of the "balance point" and effects of outliers
Task 3	Redefinition	Used DOTS to engage students with statistical concepts in a way that would not be possible without it, linking to data distributions using the "see-saw" analogy provided by the app

All lessons centered on the concept of the mean which the DOTS applet emphasizes. While these different classifications helped to describe the overall nature of the technology integration, we wanted to analyze the data further to identify *how* this integration was decided upon by each teacher. Through the development of our coding framework, we were able to identify ten categories that capture different aspects of the teachers' task design intentions. The coding framework developed through our analysis is given in Table 2.

Table 2. Coding framework developed during analysis of the teachers' written submissions.

Conceptual focus (*mean as summary value for a distribution, mean as balance point, mean vs median, effect of outliers on the mean or median*)	Curriculum alignment (*linked to curriculum standards, grade levels, or learning progressions*)
Context used (*real-life situation, no context/abstract, both real-life and no context, multiple contexts)*	Age-related considerations (*use of hands-on physical items, readiness for abstraction, accessibility of technology, device constraints for younger children*)
Learning approach (*open exploration, guided exploration, structured questions, use of sequencing and scaffolding)*	Social setting (*individual, pairs, or group at school, parent with child at home, teacher facilitation)*
Assessment opportunities *(prompts provided within task for reasoning or reflection, focus on formative assessment, calculation or distribution focused)*	Technology benefits (*visualization, experimentation, independent learning, discovery, student engagement, automation*)

Applet features utilized (*dragging dots, adding or removing dots, estimating mean by clicking, dragging mean with balance test)*	Technology interactions (*making and testing conjectures, changing things and seeing what happens, visual calculator, dynamic feedback)*

The categories and specific examples of teachers' task design decisions provided in Table 2 demonstrate the different factors considered when planning use of the DOTS applet. Excluding the *Curriculum alignment*, there appeared to be at least some consideration of the design of the technology (the DOTS applet) when describing pedagogical intent. Naturally, the ten categories are not independent from each other, as the teachers' design decisions were connected by their overall goal for the task design. For instance, the *Context used* category was developed to account for whether each teacher planned to use a real-life context for the data within the applet. Using a real-life context is supported by the DOTS applet as there is a button that allows users to name the variable.

However, the "Create a random distribution" button of the applet lends itself to generating context-free distributions. Depending on each teacher's *Conceptual focus* of the task, they made different decisions about the data contexts used. For Task 1 (designed by Teacher 1), the focus of the task was on measures of central tendency for a distribution. To engage students with the task and DOTS applet, the teacher decided to use the real-life context of Joey's test scores. Through a set of structured questions, students investigated the impact on the different measures of central tendency, for example, if Joey gained either a very low or high mark compared to his existing marks.

In contrast, for Task 2 (designed by Teacher 2), the focus was on the concept of the mean as a "balance point" of a distribution. No context was used, and the task utilized the random distribution button to support students to create and test conjectures about the value of the mean. For Task 3 (designed by Teacher 3), the context used and conceptual was influenced by *Age-related considerations*. This teacher planned to use the DOTS applet with a young child, and so decided it was not appropriate to focus on numbers (e.g., the values of the mean or median), but instead just the concept of a balance point. Using a see-saw analogy consistent with the design of the applet, the task planned to explore effects of variables like weight, distance, and movement on the balance point, including the use of physical items. As the teacher explained, "*... a physical demonstration using a spoon can be used because it has a balance point that is not intuitive to small children.*"

DISCUSSION

There are many technologies that can be integrated when teaching statistics (e.g., Ben-Zvi, 2000; Biehler, 1997b; delMas, 1997) to address well-documented student difficulties with statistical concepts (e.g., McGatha et al, 2002; Pollatsek et al., 1981). As an initial small-scale exploration, the purpose of our study was to determine whether the teachers' written submissions about how they *planned* to integrate the DOTS applet into a statistics task would provide rich and meaningful data for analysis, to advance understanding of teacher integration of interactive technology in statistics education.

One focus for our research was to investigate the value of using technology integration frameworks like SAMR (Puentedura, 2020) to classify how teachers make decisions when designing tasks for statistics. Zulfiani et al. (2025) conducted a systematic review of SAMR-related studies from 2019 to 2024 and found that most teachers' technology practices remain at the *Substitution* and *Augmentation* levels, rather than more transformative and interactive technology integrations. Within our small case study, we observed tasks that could be classified using all four levels of the SAMR framework except for *Substitution.* Although our study involved a small number of participants, through our analysis of the tasks developed by the three teachers, we have provided new SAMR-aligned examples within statistics education that could be used as part of professional development for task design that integrates technology.

Even with just three teachers, we saw diverse teaching ideas for the DOTS applet, with different goals for learning. Hence, we developed a coding framework with ten categories that appeared to capture the different aspects of the teachers' task design intentions, with many of these categories consistent with key features of effective statistical tasks involving technology (e.g., Bargagliotti & Franklin, 2015).

We expected that the teachers would describe tasks that focused on interactivity, however, there were notable differences in task design intentions, particularly with respect to how the DOTS applet would encourage student engagement. Although limited by the scale of our study, we believe our framework provides some guidance for further exploration of *how* the same technology tool can be used in different ways to support student learning, depending on the teacher's specific conceptual focus and pedagogical approach (cf. Pratt, 2008). We plan to work with teachers in both the US and New Zealand to further study the teachers' instructional decisions using the DOTS applet.

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