CREATING STUDENT AUTONOMY AND BUILDING FUNCTIONAL REASONING THROUGH AN ENTREPRENEURIAL DESIGN CHALLENGE

Erin E. Krupa
NC State University
eekrupa@ncsu.edu

Michael Belcher
NC State University
mjbelche@ncsu.edu

Margaret L. Borden
NC State University
mcleak@ncsu.edu

Ashley Loftis
NC State University
alking2@ncsu.edu

Robin K. Anderson
NC State University
randers6@ncsu.edu

At the core of engaging students in mathematics is having them use their mathematical knowledge to solve personally relevant and authentic problems. We have created entrepreneurial-based design challenges (Authors, 2019) that engage students in rich mathematics. In this paper, we report on 30 students participating in one such challenge. Students were tasked with designing a business that helps users change unwanted behaviors or develop new healthy habits through tracking and visualizing their progress. We present results to show how the challenge provided opportunities for student autonomy in their solutions and in the mathematics they utilized.

Keywords: Curriculum; Algebra & Algebraic Thinking; Affect, Emotion, Beliefs, & Attitudes

Today's K-12 students will be asked to tackle unprecedented environmental, economic, and social challenges (OECD, 2018). They will need to be able to work collaboratively and across disciplines to invent innovative, actionable, and empathetic solutions to messy problems that lack a clear solution path. "Education needs to aim to do more than prepare young people for the world of work; it needs to equip students with the skills they need to become active, responsible and engaged citizens" (OECD, 2018, p. 5). Novel curricular approaches are needed that allow students the autonomy to identify meaningful problems and innovative solution paths, establish connections between in-school learning and students' out-of-school experiences, and engage students in learning and applying targeted disciplinary content knowledge.

Researchers in STEM education have recently begun exploring strategies for leveraging entrepreneurship to connect students' out-of-school knowledge, experiences, and interests to in-school STEM learning (e.g., Authors, 2019; Moore et al., 2017). Given its popular appeal (e.g., the TV show *SharkTank*) and its emphasis on building actionable solutions to real-world problems, entrepreneurship has the potential to support engagement and learning in a STEM setting. The BLINDED project (Authors, 2019) is a novel curricular framework that situates mathematics learning within entrepreneurial pitch competitions. In this paper, we report on a group of 30 students' solutions to the BLINDED TASK, one of 18 BLINDED challenges.

Literature Review

Strategies that support student engagement include: creating a supportive, collaborative, and cognitively demanding learning environment (Lamborn et al., 1992), making content and learning activities authentic (Blumenfeld, et al., 2006), and empowering students to exercise autonomy and authority in relation to the curricular content (Helme & Clarke, 2001; Marks, 2000). Deci and Ryan (1987) refer to autonomy as "supporting choice" (p. 1024) or "encouraging them to make their own choices" (p. 1025). Providing students opportunities for autonomy is important in a mathematics classroom, where students often perceive the subject as disconnected from their cultures, lived experiences, and future aspirations (Boaler, 2002; Gutstein, 2003). Authentic tasks can establish a purpose for learning (Blumenfeld, et al., 2006) and can help students connect the content they are learning in school to situations they find important, relevant, and worth pursuing (Reschley & Christenson, 2012). Authentic activities can also empower students to incorporate their unique out-of-school identities in mathematics (Attard, 2012; Bobis et al., 2011; Helme & Clarke, 2001; Marks, 2000; Yair, 2000), which further builds their autonomy, promotes self-monitoring and persistence (Helme & Clarke, 2001; Leon et al., 2015), and supports students' "sense of control and self-worth" (Bobis et al., 2011, p. 37). Thus, a learning opportunity that leverages authentic contexts and promotes autonomy could support improvements in students' confidence and growth mindset in mathematics.

The Project Framework and Challenge

Combining features of project-based learning (Krajcik & Blumenfeld, 2006), design-based learning (Kolodner, 2002), and entrepreneurial-based learning (Yuste et al., 2014), the BLINDED project framework (Authors, 2019) was developed to leverage authentic entrepreneurial practices and open-ended design challenges to motivate the learning of specific mathematics content. Students work collaboratively to: 1) define the problem and research the context (Krajcik & Blumenfeld, 2006; Rivet & Krajcik, 2004); 2) build, test, and refine prototype solutions (Fortus et al., 2004; Razzouk & Schute, 2012); 3) demonstrate the actionability of their solutions (Lackeus, 2015; Kolodner, 2002); and 4) deliver 5-minute pitches to panels of judges (Passaro et al., 2017; Krajcik & Blumenfeld, 2006). In the BLINDED TASK challenge, students are tasked with inventing a business that helps users (individuals or companies) set and achieve goals through tracking and visualizing their progress. Students had to build, evaluate, and interpret functions that map changes in performance onto changes in a visualization. BLINDED TASK uses design criteria to connect students' real-world solutions to math-specific school learning and establish an immediate purpose for building functions. These criteria include: identifying relevant behaviors or habits to address, inventing visualizations to monitor progress towards the goal, and building functions that translate progress in the target behavior to changes in the visualization. These criteria were created to engage students in functional reasoning through the defining, testing, and refining of generalizable relationships between two co-varying quantities (Warren et al., 2006), namely student- defined measures of the target behavior and changes in the student-invented visualization.

Methods

A mixed-methods research convergent parallel design (Creswell & Plano Clark, 2017) was used to explore the students' experiences with the BLINDED TASK implementation on student autonomy and functional reasoning. Quantitative and qualitative data were collected concurrently throughout the project, analyzed separately, and then merged together to answer the following research questions: *(1) How does the autonomy afforded by the D&P framework manifest in students' solutions?, (2) How do students demonstrate functional reasoning while participating in the BLINDED TASK challenge?, and (3) How does participating in the BLINDED TASK challenge affect students' confidence and growth mindset in math?*

Sample and Procedure

The BLINDED TASK challenge was implemented across eight days in a Math 1 class with 30 7th and 8th grade students in an urban setting. The school is 100% male, 28% low-income, and 75% minority. Students participated in the challenge in teams of three or four. In launching the challenge, the teacher focused students on the United Nations Sustainable Development Goals, allowing students the autonomy to identify goals that they found relevant.

Data Collection

To allow for a complete picture of students' experiences, we collected data from a variety of sources (Cohen et al., 2011), including daily written work samples and Pitch Decks (pitch presentation slides, animations, and handwritten prototypes). Students took a pre- and post-survey with items measuring their growth mindset and confidence in math using a 6-point Likert-scale. There were three growth mindset questions from Code et al. (2016), who adapted them from a measure on general intelligence mindset (Dweck, 2008). The survey also had one item on confidence, which was adapted from self-efficacy items in Usher (2007).

Data Analysis

Qualitatively this research draws on student artifacts, specifically their daily work samples and Pitch Decks. We analyzed the documents to describe the products each team designed and the mathematics in which they engaged. We coded student products into broad categories for the type of context they selected for their business. We collected exemplar quotes and pictures from their prototypes to highlight the functional relationships in their solutions.

Quantitatively the survey data were analyzed using paired-sample *t*-tests to determine if there were significant differences in students' growth mindset or confidence after engaging in the BLINDED TASK.

Results

Autonomy in Context

During the BLINDED TASK challenge, students drew on their interests and their experiences with a number of social justice initiatives. Across the ten groups they selected the following contexts: mental health (n=4), school improvement (n=2), food waste (n=1), social media addiction (n=1), school violence (n=1), and health (n=1). The context for three student groups will be highlighted, followed by the functional reasoning for each group.

The **Against Waste** team created a solution "to reduce food waste in schools and to make people more aware about conserving and recycling food," after seeing the amount of daily trash in their school cafeteria. They used a visualization of a trash can to help schools reduce their food waste in the cafeteria. The **Discover You** team created a mental health app, because of the rising numbers they noticed in teen depression. The third team, **PoGo**, focused on school improvement, creating an app that, in their words, "...allows Teachers and Principals to track the percentage of all students in a school who are at an Economic Disadvantage (E.D.)" compared to overall performance. Their hope was that "schools will be able to see that the percentage of E.D. students at their school are struggling and make sure that students are receiving all the things they may need (such as breakfast/lunch, proper transportation, proper school materials)."

Functional Reasoning

Students utilized a variety of strategies for building functions to allow users of their product to visualize data. Below we briefly describe the products designed by the three teams and the mathematics they utilized in their solution, including their functional relationship, input variables, output variables, and rule for connecting their function to a visual representation of their solution. The **Against Waste** group created a functional relationship for food waste and trash can visualization. They used the number of bags of trash for their input and the color and appearance of a trash can via an animation for their output variable. They were able to operationalize their input variables, based on observing data from their school cafeteria. Though they did not describe an explicit rule they had all the pieces, and the context was meaningful to them. They stated, "If you are wasting too much, the visual is heaping out foods and trash, and when you reach your goal, there will be a reward animation." **Discover You** created a functional relationship for depression based on sleep, feeling of worth, and school stress. Their input variables were a measure of worth, happiness, and stress on a scale from 1-10 and number of hours of sleep. These measures come from polling their users in their app. Their output variable was a horizontal progress bar. The rule they created for depression was: [(School Stress)$\times$ -1 +Worth+Happiness+Hours of sleep]$\times$ 10/3. Their equation accounted for the input variables they identified as important factors in depression and multiplying school stress by negative one shows the students knew they had to invert the scale for stress because it is a negative factor of depression. They created a Scratch prototype for their visual, which showed a depression score as the voltage in a battery. The **PoGo t**eam built a functional relationship for the academic achievement for students with Economic Disadvantage. based on input variables from state level School Report Card data. Their output variable was a wheel and thumb and the rule they created was based on regression analysis and the Scratch coding of a visual thumbs up and down based on residual values. In their words,

> Our app uses State School Report Card for middle schools in County to gather our data onto a graph, then it transfers that information on a graph to a wheel that is color-coded based on the subject and then has a thumbs-up emoji that changes color and rotates based on how much above, at, or below the line of regression they are at.

This group used advanced functional reasoning to create their regression analysis and turn it into a convincing visual for their users.

Confidence and Growth Mindset

There were significant increases on students' self reports from pre to post in growth mindset (pre=3.20, post4.29, t=-5.17, p<0.001), and non-significant increases in confidence (pre=4.33, post4.67, t=-1.62, p=0.058). This suggests after engaging in the BLINDED TASK challenge students had a stronger disposition towards a growth mindset.

Conclusion

By providing students with an open-ended task, they had the autonomy to create their product and create their own functions. Across the ten teams, students opted to tackle specific environmental, economic, and social challenges (OECD, 2018) that were both authentic and personally meaningful. The BLINDED framework afforded students the autonomy to identify personally meaningful problems and explore unique solution paths, while also bounding the mathematics content with which they engaged. By equipping students with this autonomy, the framework created opportunities for students to see their place in the math classroom, which improved their confidence and willingness to persist when encountering difficult problems. By allowing students the autonomy to identify personally meaningful contexts, the challenge opened the space for them to actively engage in functional reasoning. Students drew on their experiences with their chosen contexts to identify, operationalize, and define relationships between authentic input variables and their corresponding output variables, namely visualizations that allow users to track progress towards a goal. Findings from this study demonstrate how providing students with the autonomy to create a solution to an authentic problem gave them confidence in their mathematical ideas and generated powerful solutions to emerging issues facing young adults.

Acknowledgments

This material is based upon work supported by the NSF under Grant No. DRL2048332. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF agency.

References

Attard, C. (2012). Engagement with mathematics: What does it mean and what does it look like?. *Australian Primary Mathematics Classroom*, *17*(1), 913.

Blumenfeld, P. C., Kempler, T. M., & Krajcik, J. S. (2006). *Motivation and cognitive engagement in learning environments*. In K. R. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp.475–488). New York: Cambridge University Press.

Boaler, J. (2002). Learning from teaching: Exploring the relationship between reform curriculum and equity. *Journal for Research in Mathematics Education*, 239–258. https://doi.org/10.2307/749740

Bobis, J., Anderson, J., Martin, A., & Way, J. (2011). A model for mathematics instruction to enhance student motivation and engagement. In *Motivation and disposition: Pathways to learning, 73rd yearbook of the National Council of Teachers of Mathematics*, 1–12.

Code, W., Merchant, S., Maciejewski, W., Thomas, M., & Lo, J. (2016). The Mathematics Attitudes and Perceptions Survey: An instrument to assess expert-like views and dispositions among undergraduate mathematics students. *International Journal of Mathematical Education in Science and Technology, 47*(6), 917–937.

Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education.* Routledge.

Creswell, J. W., & Clark, V. L. P. (2017). *Designing and conducting mixed methods research*. Sage publications.

Deci, E. L., & Ryan, R. M. (1987). The support of autonomy and the control of behavior. *Journal of personality and social psychology*, *53*(6), 1024. https://doi.org/10.1037/0022-3514.53.6.1024

Dweck, C. S. (2008). *Mindset: The new psychology of success*. Random House Digital, Inc.

Fortus, D., Dershimer, R. C., Krajcik, J., Marx, R. W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching, 41*(10), 1081–1110. DOI 10.1002/tea.20040

Gutstein, E. (2003). Teaching and learning mathematics for social justice in an urban, Latino school. *Journal for Research in Mathematics Education*, *43*(1), 37–73. https://doi.org/10.2307/30034699

Helme, S., & Clarke, D. (2001). Identifying cognitive engagement in the mathematics classroom. *Mathematics Education Research Journal, 13*(2), 133–153. https://doi.org/10.1007/BF03217103

Kolodner, J. L. (2002). Facilitating the learning of design practices: Lessons learned from an inquiry into science education. *Journal of Industrial Teacher Education, 39*(3), 9-40.

Krajcik, J. S., & Blumenfeld, P. C. (2006). Project-based learning. In K. R. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 317–333). New York: Cambridge University Press.

Lackéus, M. (2015). *Entrepreneurship in Education–What, why, when, how. Entrepreneurship 360*. Background paper. In: Paris: OECD.

Lamborn, S., Newmann, F., & Wehlage, G. (1992). The significance and sources of student engagement. *Student Engagement and Achievement in American Secondary Schools*, 11–39.

León, J., Núñez, J. L., & Liew, J. (2015). Self-determination and STEM education: Effects of autonomy, motivation, and self-regulated learning on high school math achievement. *Learning and Individual Differences, 43*, 156–163.

Marks, H. M. (2000). Student engagement in instructional activity: Patterns in the elementary, middle, and high school years. *American Educational Research Journal, 37*(1), 153–184. https://doi.org/10.3102/00028312037001153

Moore, R. A., Newton, S. H., & Baskett, A. D. (2017). The InVenture Challenge: Inspiring STEM Learning through Invention and Entrepreneurship. *International Journal of Engineering Education, 33*(1), 361–370.

Organisation for Economic Co-operation and Development (OECD). (2018). *The future of education and skills: Education 2030*.

Passaro, R., Quinto, I., & Thomas, A. (2017). Start-up competitions as learning environment to foster the entrepreneurial process. *International Journal of Entrepreneurial Behavior & Research, 23*(3), 426–445. https://doi.org/10.1108/IJEBR-01-2016-0007

Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important? *Review of educational research, 82*(3), 330–348. https://doi.org/10.3102/0034654312457429

Reschly, A. L., & Christenson, S. L. (2012). Jingle, jangle, and conceptual haziness: Evolution and future directions of the engagement construct. In *Handbook of research on student engagement* (pp. 3–19): Springer.

Rivet, A. E., & Krajcik, J. S. (2004). Achieving standards in urban systemic reform: An example of a sixth grade project-based science curriculum. *Journal of Research in Science Teaching, 41*(7), 669–692. https://doi.org/10.1002/tea.20021

Usher, E. L. (2007). *Tracing the origins of confidence: A mixed methods exploration of the sources of self-efficacy beliefs in mathematics* (Doctoral dissertation, Emory University).

Warren, E. A., Cooper, T. J., & Lamb, J. T. (2006). Investigating functional thinking in the elementary classroom: Foundations of early algebraic reasoning. *The Journal of Mathematical Behavior, 25*(3), 208–223. https://doi.org/10.1016/j.jmathb.2006.09.006

Yair, G. (2000). Educational battlefields in America: The tug-of-war over students' engagement with instruction. *Sociology of Education*, *73*(4), 247–269. https://doi.org/10.2307/2673233

Yuste, A. P., Díez, R. H., Cotano, J. B., Fernández, J. A. S., & de Diego Martínez, R. (2014). An Entrepreneurship-Based Learning Experience in Information and Communication Technologies (ICTs). In *2nd International Conference on E-Learning and E-Educational Technology*.