

EXPLORING BIOLOGY INSTRUCTORS' TECHNOLOGICAL PEDAGOGICAL  
CONTENT KNOWLEDGE IN HIGHER EDUCATION

By

Olena James

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of  
Doctorate of Philosophy in Mathematics and Science Education

Middle Tennessee State University

May 2022

Dissertation Committee:

Dr. Grant E. Gardner, Chair

Dr. Sarah Bleiler-Baxter

Dr. Jennifer Lovett

Dr. Gili Marbach-Ad

Dr. Rebecca Seipelt-Thiemann

## Dedication

I dedicate this dissertation to my best friend, the love of my life, my husband, Delano and our wonderful children Delaya, Delano II, and Olivia.

Delano, thank you for the love and support you've shown me during this dissertation journey. Thank you for always believing in me, and motivating me to pursue my dreams.

Delaya, Delano II, and Olivia thank you for all your warm hugs and encouraging words. I pray that this process has shown you that with God anything is possible.

## Acknowledgments

I want to first give honor to God because without him this would not be possible. I am grateful for everyone he placed in my life to support me throughout my journey.

I would like to give a special thanks to my Chair, Dr. Grant E. Gardner, thank you for your guidance, support, and leadership throughout my development as a biology education researcher. To my committee members, Dr. Sarah Bleiler-Baxter, Dr. Jennifer Lovett, Dr. Gili Marbach-Ad, Dr. Rebecca Seipelt-Thiemann thank you for supporting my work and helping me further develop as a scholar. Thank you all for your commitment, feedback and advice throughout this process.

Next, thanks to the MSE community for supporting me over the past four years. Thank you for your friendship, continued support, and insight.

To my church family, thank you for the thoughtful prayers, kinds words, and motivational talks. Special thanks to Dr. Reverend Marcia Clinkscale, thank you for your love and mentorship.

To my parents, thank you for always loving and supporting me through every aspect of my life. I would not be the woman I am today without your love and support. Thank you so much for your encouragement throughout my doctoral program.

Last but certainly not least, special thanks to all my family and friends. Thanks for the laughs, hugs and prayers. Thank you, thank you, and thank you!

## Table of Contents

List of Figures .....	vii
List of Tables.....	viii
Abstract.....	1
CHAPTER I: INTRODUCTION .....	2
Purpose of Study .....	6
Research Questions .....	7
References .....	9
CHAPTER II: REVIEW OF LITERATURE A systematic literature review: How higher education faculty develop their technological pedagogical content knowledge .....	14
Introduction .....	15
Research Questions .....	20
Methods .....	21
Results .....	23
Discussion .....	36
Conclusion and Areas for Future Research.....	39
References .....	40
CHAPTER III: STUDY 1 .....	46
Technological Pedagogical and Content Knowledge Development in Biology Instruction: Measuring Biology Instructors' Technology Integration .....	46
Introduction .....	47
Theoretical Framework and Review of Literature .....	49
Research Questions .....	61
Methods.....	61

Data Analysis .....	70
Results .....	72
Discussion .....	92
Conclusion.....	98
References .....	99
CHAPTER IV: STUDY 2 Biology Instructors' New Approaches to Teaching After the Covid-19 Pandemic .....	106
Abstract .....	106
Introduction .....	107
Analytical Framework.....	118
Methods.....	122
Data Organization.....	123
Data Analysis .....	125
Credibility and trustworthiness .....	127
Results .....	127
Discussion .....	149
Limitations of the Study .....	153
Conclusion and Implications for Future Work.....	153
References .....	156
CHAPTER V: DISCUSSION .....	162
<i>Chapter II: Systematic Literature Review</i> .....	163
Chapter III: Instructors TPACK and Technology Integration .....	164
Chapter IV: Approaches to Teaching During Covid-19 .....	165
Conclusion.....	166

References .....	168
APPENDIX A: Overview of Studies Included in Systematic Review.....	171
APPENDIX B: Modified HE-TPACK Survey.....	173
APPENDIX C: Technology Integration Evaluation Scores & Criteria.....	196
APPENDIX D: Interview Protocol .....	198
APPENDIX E: <i>A priori Codebook (Rupnow et al., 2020)</i> .....	199

## List of Figures

Figure 2-1. The Seven Components TPACK.....	17
Figure 2-2. Review Process.....	22
Figure 3-1. TPACK Framework.....	51
Figure 3-2. Technology Integration Matrix.....	60
Figure 3-3. Ed Tech Frequency.....	79
Figure 3-4. TPACK Score per Participant.....	82
Figure 3-5. TPACK Score by Instructor Type.....	84
Figure 3-6. Technology Integration.....	86
Figure 3-7. TIM Score by Instructor Type.....	87
Figure 3-8. Scatter Plot.....	89
Figure 3-9. Hierarchical Cluster.....	90
Figure 4-1. Teacher-Centered Systemic Reform.....	120
Figure 4-2. TCSR Model.....	121
Figure 4-3. Percentages of Frequency Codes.....	129

## List of Tables

Table 2-1. Overview of Survey Instruments.....	24
Table 3-1. HE-TPACK Survey Breakdown.....	65
Table 3-2. Cronbach's Alpha Summary .....	66
Table 3-3. Participant Demographics.....	73
Table 3-4. CFA Factor Loadings.....	74
Table 3-5. Codebook Ed Tech.....	78
Table 3-6. Code Co-Occurrence Ed Tech.....	80
Table 3-7. TPACK Descriptive Statistics.....	83
Table 3-8. ANOVA TPACK.....	84
Table 3-9. ANOVA TIM.....	88
Table 3-10. Results of Cluster Analysis.....	90
Table 3-11. Cluster Profiles.....	90
Table 4-1. Interview Questions & Discussion Topics.....	125
Table 4-2. Demographics. ....	128
Table 4-3. Code Table Reflecting on Rapid.....	131
Table 4-4. Code Table Reflecting Impact of Pandemic.....	139
Table 4-5. Code Table Reflecting New Teaching Practices.....	143

## Abstract

With the rapid emergence of educational technology in learning environments, instructors' development of technology knowledge is necessary to select educational technologies for effective instruction. Online courses have also shown steady growth in higher education institutions over the past two decades. More recently, the rapid shift to online instruction in March 2020 increased the need for more online course offerings. The rapid shift to online instruction may have required significant change in instructional practice for science instructors because of the content and laboratory components. The growing use of educational technologies in higher education combined with an increased demand for online courses has reshaped how instructors, students, and technologies interact. Components of effective integration of educational technology require instructor knowledge of the technology, instructor knowledge of the disciplinary content associated with the technology, and the knowledge of instructional strategies to integrate the educational technology and content holistically, commonly known as Technological Pedagogical and Content Knowledge (TPACK) (Mishra, & Koehler, 2006). The TPACK framework can assist researchers in better understanding instructors' technology knowledge and teacher practice in integrating educational technology in online courses. This mixed-method study first explored biology instructors' TPACK and technology integration and if there is a relationship between the two, and then explored biology instructors' teaching experiences online during the COVID-19 pandemic Spring 2020 semester, and the impact if any it had on their teaching practices. Through the lens of TPACK, this study explored what factors contributed to biology instructors' technology integration and how those factors impacted online teaching.

## CHAPTER I: INTRODUCTION

Since the beginning of the 21st century, technological advances have been integrated into curriculum and instruction in higher education classrooms to engage students and facilitate their learning (Kopcha, 2010; National Research Council, 2012; P21 Partnership for 21st Century Learning, 2016). Classroom technology to support student learning is commonly known as educational technology. The accelerated pace of technological innovation in recent years has created a need for educational research to provide additional evidence on how learning is best supported by emerging educational technologies that continually change learning environments and student engagement with content (Oliveira et al., 2019). This scholarly need is particularly strong in science, a discipline that shares a synergetic relationship with educational technology and therefore often results in the use of educational technology in the classroom (Bernhard, 2012; Ihde, 2009; Oliveira et al., 2019).

According to Bernhard (2012), science is a production of knowledge and is technologically embodied. This means that science uses technology as not only an instrument but also for innovation and information (Oliveira et al., 2019). The perception of science by instructors is co-determined by technology, but technology uses the theories of science (Bernhard, 2012). One cannot truly experience science without experiencing its technological dimension and thus educational technologies and science classrooms have a unique relationship in contrast to other disciplines (Jones, 2019; Oliveira et al., 2019).

As a result, emergent educational technologies have increasingly shaped students'

experiences with learning science. Although educational technologies can enhance student learning, they do not always reach their full pedagogical potential when instructors do not use them with efficacy or integrate them effectively into instruction (Lim et al., 2013; Voogt et al. 2013). Some predictors of effective integration of educational technology in instruction are the amount of instructor knowledge of the technology, instructor knowledge of the disciplinary content associated with technology, and the knowledge of the instructional strategies to integrate the educational technology and content holistically. This knowledge collectively is known in the literature as Technological Pedagogical And Content Knowledge (TPACK) (Mishra & Koehler 2006). The dissertation research is focused on instructor TPACK and its impact on teaching and learning.

For this dissertation, the analysis of instructor TPACK is embedded in the disciplinary science of biology. There is recognition among many educational technologists that the pedagogical uses of educational technology are strongly influenced by the content domains in which they are situated, even between the science domains (Chang & Wei, 2016; Jang, 2010). For example, the instructor's pedagogical content knowledge required to effectively integrate educational technology in a general biology classroom may be very different from that required for a general physics classroom (Graham et al., 2009; Wu, 2016; Yeh, 2014). More specifically, general physics teaching might emphasize facts, physical concepts, and the use of formulas to solve physics problems (Mulhall & Gunstone, 2008). On the other hand, general biology teaching might focus more on facts and abstract biological concepts, more so than on problem -

solving (Cimer, 2012). Nurdiani et al. (2019) highlight that in biology courses the numerous abstract concepts and processes are often not easily understood by students. One way that visualization of abstract concepts by students can be more concrete, detailed, and systematic can be done with the appropriate educational technology. In fact, educational technologies to support student visualization are common in life science classrooms (Oliveria et al., 2019). Irdalisa et al. (2020) suggest instructors' pedagogical content knowledge is important because it determines specific instructional methods and the appropriate use of educational technologies for that particular disciplinary field. This is supported by the role of content knowledge inherently within the TPACK Framework. An understanding of instructors' TPACK cannot be separated from the discipline in which they might teach. The nature of facts, concepts, and theories differs according to disciplinary subject matters, which is one of the reasons why TPACK should be domain-specific (Harris et al., 2017; Kiray, 2016; Yeh, 2014).

This research focused on online courses as the learning environment for two major reasons. First, online courses have shown steady growth in higher education institutions over the past two decades (Allen et al., 2013; Allen et al., 2016; Brinkley-Etzkorn, 2018). Higher education institutions continue to increase their online courses offered to meet the needs of an increasingly growing student population with varying needs (Allen et al., 2016; Kampov-Polevoi, 2010; Meyer et al., 2014; Ouyang et al., 2018). The growing use of educational technologies in higher education in addition to the increased demand for online courses has reshaped how instructors, students, and technologies interact (Kelsey et al., 2020; Richardson et al., 2020). Second, the rapid shift

to online instruction in early March 2020, due to the COVID-19 pandemic, was an unprecedented time for college and university instruction (Kelsey et al., 2020; Rupnow et al., 2020; Zuckerman et al., 2021). During Spring 2020, instructors had to learn new teaching practices to transform their regular face-to-face classes into online in a matter of weeks (Rupnow et al., 2020). Both the increase in online instruction and its interface with educational technologies, coupled with the increased numbers of faculty having to move to online instruction during March 2020 made it an ideal instructional context to explore instructor TPACK.

The rapid move to online instruction within the context of biology may have required a significant change in instructional practice than in other non-science disciplines because of the abstract content and laboratory components of many science courses (Darling-Hammond et al., 2020). Quality online teaching requires choosing pedagogical practices that help overcome inherent challenges (e.g., student engagement) (Darling-Hammond et al., 2020; Scoppio & Luyt, 2017). In biology, instructors have started to try various educational technologies to facilitate learning online, which includes having students collect, measure, and analyze data to model, simulate and visualize biological phenomena (Zuckerman et al., 2021). The quality of online biology learning environments varies among institutions and instructors (Cleveland et al., 2017). It was essential to understand how the rapid shift to online teaching shifted biology instructors perceptions of their teaching practices and experiences as well as what impacted their technology integration and overall TPACK (Rad et al., 2021; Zuckerman et al., 2021).

In summary, educational technologies are rapidly changing and perhaps this

impact is felt more strongly in science classrooms. This issue remains that effective integration of these educational technologies to promote student learning in online science classrooms is still lacking. One cause for this ineffective use of educational technologies by science instructors is their lack of technological pedagogical and content knowledge (TPACK). The development of online science instructors' TPACK has rarely been explored in the literature, which lead to the dissertation research discussed below.

### **Purpose of Study**

As noted above, one cannot study instructor TPACK without deep disciplinary consideration of the instructors' content knowledge. As such, this study is embedded in the disciplinary content of biology. There is an abundance of research surrounding the TPACK of biology instructors in K-12 settings (Juanda et al., 2021; Muhammad et al., 2020). TPACK is noted as a critical component for K-12 pre-service biology teachers to improve the integration of technology in their teaching and learning practices (Blonder et al., 2013; Lee & Tsai, 2008; Lin et al., 2012). However, presently not much is known about the TPACK of biology instructors in higher education. This could be concerning because these are the instructors who teach the future K-12 biology teachers (Gonzales, 2018; Narulita et al., 2019). There is a need to investigate biology instructors' TPACK and technology integration levels now in particular because of the rapid advances and use of educational technology in biology and the shift to more online learning due to the global pandemic that occurred from Spring 2020 to Fall 2021 academic semesters (Chen et al., 2018; Pacheco-Guffrey, 2021). For these reasons, it is important that research more thoroughly think about the interaction between educational technology integration and higher education biology instructors' TPACK.

Based on recommendations from Irdalisa et al. (2020), Nurdiani et al. (2019), and other biology education researchers, there is a need to address experiences and perceptions of biology instructors' TPACK development and technology integration across institutions. Using the TPACK Framework (discussed in more detail in Chapter II), the goal of this research was to identify biology instructors' TPACK and experiences using educational technologies before, and during the COVID-19 pandemic. This study used the technology integration matrix (discussed in more detail in Chapter III) to explore the technology integration of biology instructors related to their perceived TPACK (Florida Center for Instructional Technology, 2005). Also, the Teacher-Centered Systemic Reform (TCSR) Model was used (discussed in more detail in Chapter IV) to explore biology instructors' new teaching practices online (Gess-Newsome et al., 2003). This data will be used to further explore TPACK and educational technology integration perceptions to inform implications for professional development opportunities for post-secondary biology instructors related to educational technology integration.

### **Research Questions**

This mixed-methods dissertation research examined biology instructors' TPACK as it related to technology integration and how its integration translates online. The dissertation is composed of three stand-alone articles (Chapter II, Chapter III, and Chapter IV) that examine the following research questions:

**Chapter II:** A Systematic Literature Review: How Higher Education Faculty Develop Their Technological Pedagogical Content Knowledge

RQ1: How has higher education faculty TPACK been measured and assessed?

RQ2: How do higher education faculty develop their TPACK?

### **Chapter III: Technological Pedagogical Content Knowledge Development in Biology**

Instruction: Measuring Biology Instructors' Technology Integration Levels

RQ1: How do biology instructors define educational technology?

RQ2: What is the technological pedagogical content knowledge (TPACK) of biology instructors at higher education institutions?

RQ2a: How does TPACK differ by instructor type?

RQ3: What are biology instructors at higher education institutions perceived technology integration levels?

RQ3a: How do technology integration levels differ by instructor type?

RQ4: How does TPACK influence biology instructors' technology integration?

### **Chapter IV: Biology Instructors' New Approaches to Teaching After the Covid-19 Pandemic**

RQ1: What were Biology instructors' experiences teaching online during the COVID-19 pandemic?

RQ2: What teaching practices did biology instructors sustain after their initial online experiences?

## References

- Allen, D., Brown, A., Karanasios, S., Norman, A. (2013). How should technology-mediated organizational change be explained? A comparison of the contributions of critical realism and activity theory. *MIS Quarterly*, 37, 835-854.
- Allen, G., Guzman-Alvarez, A., Molinaro, M., & Larsen, D. (2015). Assessing the impact and efficacy of the open-access ChemWiki textbook project. *Educause Learning Initiative Brief*. <https://net.educause.edu/ir/library/pdf/elib1501.pdf>
- Angeli, C., & Valanides, N. (2009). Epistemological and methodological issues for the conceptualization, development, and assessment of ICT-TPCK: Advances in technological pedagogical content knowledge. *Computers & Education*, 52, 154-168. <https://doi:10.1016/j.compedu.2008.07.006>
- Astuti, F. Paidi E. (2019). Developing an observation instrument to measure technological pedagogical knowledge (tpk) of biology teacher in learning process. *Journal of Physics: Conference Series*, 1241.
- Bernhard, J. (2012). Learning through artifacts in engineering education. In N. M. Seel (Ed.), *Encyclopedia of the sciences of learning*, 1983–1986. Germany: Springer.
- Blonder, R. Jonathan, M., Bar-Dov, Z., Benny, N., Rap, S. and Sakhnini, S. (2013). Can you tube it? Providing chemistry teachers with technological tools and enhancing their self-efficacy beliefs. *Chemistry Education Research and Practice*, (3). <https://doi.org/10.1039/D0RP00291G>
- Brinkley- Etzkorn, K. (2018). Learning to teach online: Measuring the influence of faculty development training on teaching effectiveness through a TPACK lens. *The Internet and Higher Education*, 38, 28-35. <https://doi.org/10.1016/j.iheduc.2018.04.004> .
- Chai, C., Koh, J., & Tsai, C. (2013). A review of technological pedagogical content knowledge. *Educational Technology & Society*, 16 (2), 31–51.
- Chang, J., & Wei, H. (2016). Exploring engaging gamification mechanics in massive online open courses. *Journal of Educational Technology & Society*, 19(2), 177-203.
- Chen, M. M., Scott, S. M., & Stevens, J. D. (2018). Technology as a tool in teaching quantitative biology at the secondary and undergraduate levels: a review. *Letters in biomathematics*, 5(1), 30–48. <https://doi.org/10.1080/23737867.2017.1413432>
- Cimer, A. (2012). What makes biology learning difficult and effective: Students’ views? *Educational Research and Reviews*, 7, 61-71.
- Cleveland, L., Olimpo, J., & DeChenne-Peters, S. (2017). Investigating the relationship between instructors’ use of active-learning strategies and students’ conceptual understanding and affective changes in introductory biology: A comparison of two active-learning environments. *CBE—Life Sciences Education*, 16(2).
- Cruikshank et al., 2012 Cruikshank, D. R., Jenkins, D. B., & Metcalf, K. K. 2012 *The Act Of Teaching: Sixth Edition* (New York: McGraw Hill) 3-14

- Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science, 24*(2), 97-140.
- Depape, F., Verschaffel, L., & Kelchtermans, G. (2013). Pedagogical content knowledge: A systematic review of the way in which the concept has pervaded mathematics educational research. *Teaching and Teacher Education, 34*, 12-25. <https://doi.org/10.1016/j.tate.2013.03.001>
- Florida Center for Instructional Technology. (2005-2020). *The technology integration matrix: Adaptation level*, para. 2, University of South Florida, College of Education. Retrieved from <https://fcit.usf.edu/matrix/project/adaptation-level/>.
- Gess-Newsome, J., Southerland, S. A., Johnston, A., & Woodbury, S. (2003). Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching. *American Educational Research Journal, 40*(3), 731-767.
- Gonzales, A. (2018). Exploring technological, pedagogical, and content knowledge (TPACK) and self-efficacy belief of senior high school biology teachers in batangas city. *The Palawan Scientist, 10*, 29 – 47.
- Graham, C., Burgoyne, N., Cantrell, P., Smith, L., Clair, L., and Harris, R. (2009). TPACK development in science teaching: Measuring the TPACK confidence of in-service science teachers. *Tech-Trends, 53*(5), 70-79.
- Griffin, L., Dodds, P., & Rovegno, I. (1996). Pedagogical content knowledge for teachers: Integrate everything you know to help students to learn. *Journal of Physical Education Recreation & Dance, 67*, 58-61.
- Harris, J., Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60-70.
- Harris, J., Phillips, M., Koehler, M., Rosenberg, J. (2017). TPCK/TPACK research and development: Past, present, and future directions. *Australasian Journal of Educational Technology, 33*(3).
- Hadiyanti, L., Widodo, A., Rochintaniawati, D. and Riandi, R. (2014). Pedagogical content knowledge of experienced and prospective biology teachers *Paper Presented in UPI–UPSI Conference*
- Ihde, D. (2009). *Postphenomenology and technoscience: The Peking university lectures*. Albany, NY: State University of New York Press.
- Irdalisa, I., Paidi, H., & Djukri, D. (2020). Implementation of Technology-based guided inquiry to improve TPACK among prospective biology teachers. *International Journal of Instruction, 13*(2), 33-44. <https://doi.org/10.29333/iji.2020.1323a>
- Irmak, M. & Tüzün, Ö. (2019). Investigating pre-service science teachers' perceived technological pedagogical content knowledge (TPACK) regarding genetics, *Research in Science & Technological Education, 37*(2), 127-146, <https://doi.org/10.1080/02635143.2018.1466778>.
- Jang, S., & Chen, K. (2010). From PCK to TPACK: Developing a transformative model for pre-service science teachers. *Journal of Science Education and Technology, 19*(6), 553-564. <https://doi.org/10.1007/s10956-010-9222-y>
- Jose, M., Bonete, G., Jensen, M., Katona, G. (2018). A practical guide to developing

- virtual and augmented reality exercises for teaching structural biology. *Biochemistry and Molecular Biology Education*, 47(1), 16–24.
- Juanda, A., Shidiq, A. S., & Nasrudin, D. (2021). Teacher Learning Management: Investigating Biology Teachers' TPACK to Conduct Learning During the Covid-19 Outbreak. *Journal of Pendidikan IPA Indonesia*, 10(1), 48-59.
- Kampov-Polevoi, J. (2010). Considerations for supporting faculty in transitioning a course to online format. *Online Journal of Distance Learning Administration*, 13(2).
- Kiray, S. (2016). Development of a TPACK self-efficacy scale for preservice science teachers. *International Journal of Research in Education and Science (IJRES)*, 2(2), 527- 541.
- Koehler, M. & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, 9(1), 60-70.
- Kopcha, T.J., Ottenbreit-Leftwich, A., Jung, J., Baser, D. (2014). Examining the TPACK framework through the convergent and discriminant validity of two measures. *Computers and Education*, 78.
- Lee, H, Tsai, H, Yu, H. (2008). Developing the digital content industry in Taiwan. *Review of Policy Research*, 25(2).
- Lemoine, P., Richardson, M. (2020). Planning for higher education institutions: Chaos and the COVID-19 pandemic. *Educational Planning*, 27(3), 43-57.
- Lim, C. P., Zhao, Y., Tondeur, J., Chai, C., and Tsai, C. (2013). Bridging the gap: Technology trends and use of technology in schools. *Educational Technology & Society*, 16(2), 59–68.
- Lin, T., Tsai, C., Chai, C. (2013). Identifying science teachers' perceptions of technological pedagogical and content knowledge (TPACK). *Journal Science Education Technology*, (22), 325–336. <https://doi.org/10.1007/s10956-012-9396-6>
- Meigs, R. (2010). *Development and pilot of the technology integration matrix questionnaire*. (Published dissertation). Baker University, Bladwin City, Kansas.
- Meyer, A., Rose, D. H., & Gordon, D. (2014). *Universal design for learning: Theory and practice*. Wakefield, MA: CAST
- Mishra, P., & Koehler, M. (2006). Technological pedagogical content knowledge: A framework for integrating technology in teacher knowledge. *Teachers College Record*, 108(6), 1017–1054.
- Muhammad, H., Metiza, M., Elda, H. (2020). Relationships between teaching experience and teaching ability with TPACK: perceptions of mathematics and science lecturers at an Islamic university. *Journal of Science Learning*, 4(1), 1-7.
- Mulhall, P., & Gunstone, R. (2008). Views about physics held by physics teachers with differing approaches to teaching physics. *Research in Science Education*, 38(4), 435-462.
- Narulita, E., Hariyadi, S., Utomo, A., and Fauziah, L. (2019). Research-based biotechnology book with virtual laboratory for elevating TPACK of biology pre-service teacher. *International Journal of Learning, Teaching and Educational Research* 18(11), 297-310. <https://doi.org/10.26803/ijlter.18.11.18>

- National Research Council. (2012). Improving Measurement of Productivity in Higher Education. The National Academies Press. <https://doi.org/10.17226/13117>.
- Nurdiani, N., Rustaman, N., Setiawan, W. and Priyandoko, D. (2019). The IM and LMS moodle as the TPACK components in improving embryology concepts mastery of prospective biology teachers. *AIP Conference Proceedings* 2120, 060012. <https://doi.org/10.1063/1.5115712>.
- Oliveira, A., Feyzi Behnagh, R., Burgess, K., Guo, L. (2019). Emerging technologies as pedagogical tools for teaching and learning science: A literature review. *Uses of Emerging Technologies, Special Issue Article*, <https://doi.org/10.1002/hbe2.141>
- Ouyang, F., & Scharber, C. (2018). Adapting the tpack framework for online teaching within higher education. *International Journal of Online Pedagogy and Course Design*, 8(1).
- P21, Partnership for 21st Century Learning (2016). P21 Framework Definitions. Retrieved from <http://www.p21.org/our-work/resources/for-educators>.
- Pacheco-Guffrey, H. (2021). Cultivating Digital Literacy. *Science and Children*, 58(5).
- Putri, A., Hidayat, T., & Purwianingsih, W. (2020). Analysis of technological pedagogical content knowledge (TPACK) of biology teachers in classification of living things learning. *Journal of Physics: Conference Series*. 1521, 042033.
- Rad, F., Otaki, F., Baqain, Z., Zary, N., & Al-Halabi, M. (2021). Rapid transition to distance learning due to COVID-19: Perceptions of postgraduate dental learner and instructors. *Plos one*, 16(2), e0246584.
- Richardson, E. (2020). Pandemicity, COVID-19 and the limits of public health ‘science.’ *BMJ Global Health*, 5.
- Rupnow, R., LaDue, N., James, N., & Bergan-Roller, H. (2020). A perturbed system: How tenured faculty responded to the COVID-19 shift to remote instruction. *Journal of Chemical Education*, 97(9), 2397-2407.
- Santos, J., & Castro, R. (2021). Technological pedagogical content knowledge (TPACK) in action: Application of learning in the classroom by pre-service teachers (PST); *Social Sciences & Humanities*, 3(1).
- Scoppio, G., & Luyt, I. (2017). Mind the gap: Enabling online faculty and instructional designers in mapping new models for quality online courses. *Education and Information Technologies*, 22(3), 725-746.
- U.S. Department of Education, Office of Educational Technology. (2017). Reimagining the role of technology in higher education: A supplement to the national education technology. <https://tech.ed.gov/files/2017/01/Higher-Ed-NETP.pdf>.
- Voogt et al. 2013). Voogt, J., Fisser, P., Roblin, N., ParejaTondeur, J., and van Braak, J. (2013). Technological pedagogical content knowledge—A review of the literature. *Journal of Computer Assisted Learning*, 29(2), 109-121.
- Wu, J. (2016). Learning through Video Production - an Instructional Strategy for Promoting Active Learning in a Biological Course. In S. Barker, S. Dawson, A. Yeh, Y., Hsu, Y., Wu, H., Hwang, F., and Lin, T. (2014). Developing and validating technological pedagogical content knowledge-practical (TPACK-practical) through the Delphi survey technique. *British Journal of Educational Technology* 45 (4), 707–722. <https://doi.org/10.1111/bjet.12078>

Zuckerman, A. L., Hardesty, R. A., Denaro, K., Lo, S. M., & Owens, M. T. (2021). Effects of remote teaching in a crisis on equity gaps and the Constructivist learning environment in an introductory biology course series. *Journal of microbiology & biology education*, 22(1), 2211-2293.

**CHAPTER II: REVIEW OF LITERATURE**  
**A systematic literature review: How higher education faculty develop their  
technological pedagogical content knowledge**

*Under Review:*

James, O<sup>1</sup>, Gardner, G<sup>2</sup>. (under review). A systematic literature review: How higher education faculty develop their technological pedagogical content knowledge. *Educational Research Review*.

**Abstract**

With the rapid emergence of educational technology in higher education learning environments, higher education faculty's development of technology knowledge is necessary to select appropriate technologies for effective instruction. Integrating educational technologies with fidelity in the classroom is a primary concern in many institutions of higher education. Effective implementation of educational technology requires instructor knowledge of the technology, instructor knowledge of the disciplinary content associated with the technology, and the knowledge of instructional strategies to integrate the educational technology and content holistically. These knowledge bases are collectively known as Technological Pedagogical Content and Knowledge (TPACK) (Mishra, & Koehler, 2006). There is little work and consistency in how this construct has been measured in higher education contexts. As such, we synthesize how TPACK has been measured utilizing surveys, interview protocols, and artifacts and critique the validity and reliability of evidence for each. Finally, we synthesize the findings related to the development of TPACK in higher education faculty following experiences in various forms of professional development including lesson redesigns, one-on-one consultations, and co-teaching.

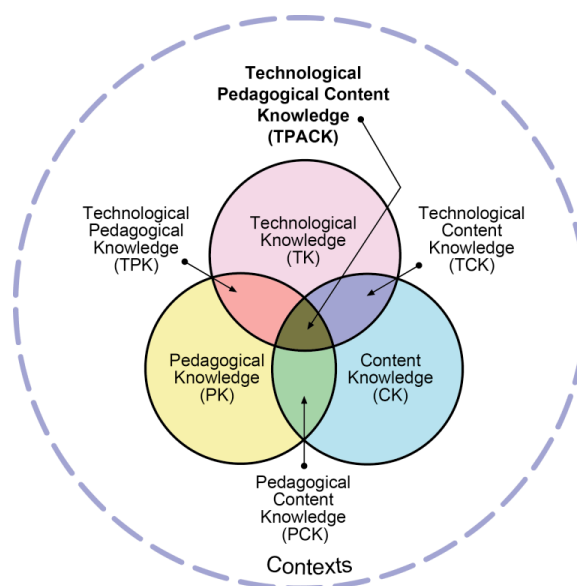
**Introduction**

The rapid emergence of new educational technologies to support student learning in higher education has made instructor knowledge of these technologies increasingly important for effective instruction (Graham et al., 2009; National Research Council, 2012; P21 Partnership for 21st Century Learning, 2016). Faculty development of technological knowledge is necessary to select appropriate educational technologies to effectively integrate into curriculum and instruction (Yilmaz et al., 2020). Integrating educational technologies effectively in the classroom is a primary concern in many institutions of higher education because online courses have shown steady growth over the past two decades (Allen et al., 2013; Allen et al., 2016; Brinkley-Etzkorn, 2018). Higher education institutions continue to increase their online courses offered to meet the needs of the student population (Allen et al., 2016; Kampov-Polevoi, 2010; Meyer et al., 2014; Ouyang et al., 2018). During the last few years, the COVID-19 pandemic has only accelerated the use of online instructional environments. The growing use of educational technologies in higher education combined with an increased demand for online courses has reshaped how instructors, students, and technologies interact (Richardson et al., 2020).

Although for many instructors educational technology is somewhat intuitive, in reality, educational technology is hard to define. In general, the word “technology” refers to both a process and a result of science. According to Bernhard (2012), science is a production of knowledge and is technologically embodied. This means that science uses technology as not only an instrument but also as innovation and information (Oliveira et al., 2019). The perception of science by instructors is co-

determined by technology, but technology uses the theories of science (Bernhard, 2012). In addition, technological developments provide the tools used in many forms of scientific study and experimentation (National Research Council, 2012). Education researchers define educational technology as technological tools, media, and learning management systems that enhance approaches to teaching (Dysart & Weckerle, 2015; Faizan et al., 2019; Foulger et al., 2015). In the context of this research, educational technology is defined as any technology that helps facilitate teaching and learning by using and managing appropriate software and hardware (Anwaruddin, 2015; Pedrosa-de-Jesus et al., 2014; Spector, 2015; Tang & Tsai, 2016).

Educational technologies can enhance student-learning outcomes, however, if the technologies are not successfully assimilated into curriculum and instruction, they are not as effective at promoting student learning (Abrams et al., 2008; Lim et al., 2013; Neumann & Horwitz, 1997). Some predictors of effective integration of educational technology are the level of instructor knowledge of (1) the technology itself, (2) the disciplinary content associated with the technology, and (3) the instructional strategies to integrate the educational technology and content holistically. The combination of the three knowledge components is commonly known as Technological Pedagogical and Content Knowledge (TPACK) (Koehler, 2011; Mishra & Koehler, 2006). (See Figure 2-1).

**Figure 2-1***The Seven Components of the TPACK Framework*

*Note.* Adapted from: What is technological pedagogical content knowledge? Koehler, M. & Mishra, P., 2009.

Over a decade of research has focused on K-12 teacher TPACK development as it relates to educational technology integration and validation of the TPACK Framework (Blonder et al., 2013; Guzey & Roehrig, 2009; Jang, 2010; Mishra & Koehler 2006). However, in K-12 settings there is not much consistency in the way TPACK is measured making it difficult to draw consistent conclusions about teacher development of TPACK across studies (Schmidt et al., 2020). Much less research has been conducted in higher education contexts. Faculty and higher education institutions have a growing interest in incorporating educational technology into instruction, but collegiate workloads are often quite different than K-12 workloads (Bichsel, 2013; Wilkin et al., 2013). Compared to K-12 teachers, higher education faculty often have a different distribution of work responsibilities (i.e. campus service, student advising, teaching-related activities), and

have a wider diversity of pedagogical approaches that correlate with their specific content in their discipline (i.e., interactive lectures, laboratory instruction, field instruction) (Kinchin, 2012; National Research Council, 2012; Wu, 2016). In recent years, researchers have realized the importance of higher education faculty training to integrate educational technology into their teaching practices (Rienties, et al., 2013). Chai et al. (2013) proposed that more studies in higher education settings should be carried out to understand faculty perspective and integration of technology, pedagogy, and content knowledge.

The first purpose of this manuscript is to investigate, analyze, and synthesize previous research that has explored how higher education faculty TPACK is measured. We do this to provide the groundwork for understanding the consistency and inconsistency in TPACK construct measurement. Second, we were interested in better understanding how higher education faculty develop TPACK and the impacts this professional development has on future teaching utilizing educational technologies. The first section of this paper gives an overview of the TPACK Framework to situate the synthesis. The second section outlines the methods used to search the literature for the systematic review. The third section gives a detailed description of findings related to higher education faculty TPACK measurement, and professional development. Lastly, the trends across literature and future research directions are provided.

#### *TPACK Framework*

The TPACK Framework begins with three distinct knowledge domains (i.e., technological, pedagogical, and content knowledge) and posits an intersection of these three (Chai et al., 2008; 2013; Harris et al., 2009; Koehler & Mishra, 2008). For

pedagogical and content knowledge, the TPACK Framework builds on Shulman's (1986) construct of pedagogical content knowledge (PCK). Pedagogical Knowledge (PK) is defined as the specialized knowledge that teachers draw upon when constructing and facilitating teaching and learning environments that are effective for all students, independent of the subject (Guerriero, 2017). Content Knowledge (CK) is knowledge of the facts, concepts, and theories taught and learned in a specific subject discipline (Griffen et al., 1996; Guerriero, 2017). PCK is the knowledge teachers use to translate particular subject content to students while taking into account possible student alternative conceptions, the learning environment, and learning activities (Angeli & Valanides, 2009; Depaepe et al., 2013; Griffin et al., 1996; Shulman, 1986).

Teachers who have strong PCK understand concepts associated with the subject matter they are teaching, the ways the concepts can be represented and formulated by students, effective pedagogical techniques for teaching the disciplinary concepts, and can evaluate students' existing knowledge about the concepts (Mishra & Koehler, 2006). By having strong PCK, teachers can support students in developing an understanding of specific disciplinary content (Shulman, 1986). To help further capture the complexity of instructor knowledge in diverse learning environments, the TPACK Framework added the knowledge of technology domains to Shulman's (1986) original PCK framework (Figure 2-1). The TPACK Framework includes knowledge about different technologies (TK); understanding, and communicating representations of disciplinary concepts using technologies (TCK); and pedagogical techniques used during a lesson using technology (TPK). Also, the TPACK Framework includes the knowledge of whether concepts are difficult or easy to learn with technology, and knowledge of how technology can develop

students' thinking and learning in a specific content area (TPACK; Harris et al., 2009). Mishra and Koehler (2006) stated that the TPACK Framework emphasizes the connections, interactions, affordances, and constraints between and among the three primary domains (PK, CK, and TK) and should not be treated as separate bodies of knowledge.

Because an instructor's TPACK requires complex interactions of multiple knowledge domains, it is often difficult but critical for teachers to develop TPACK to effectively integrate educational technology into their teaching practices (Jang, 2010; Schmidt et al., 2009; Wahono & Chang, 2019). Higher education institutions have started to respond to this potential increased need for faculty TPACK development by providing adequate training and staff support for faculty development. This is to increase faculty awareness of the complex interplay between educational technology, pedagogy, and content knowledge in their disciplines (Löfström & Nevgi 2008; Rienties et al. 2011; Rienties & Townsend, 2012) and to increase and encourage faculty educational technology integration in their classrooms (Bichsel, 2013; Dysart & Weckerle, 2015; Grajek & Rotman, 2014). This review samples articles related to higher education faculty across multiple disciplines to synthesize what is known about this group's TPACK development and provide evidence-based directions to move this area of research and practice forward. Using the literature as evidence, this review is guided by two research questions:

### **Research Questions**

1. How has higher education faculty TPACK been measured and assessed?
2. How do higher education faculty develop their TPACK?

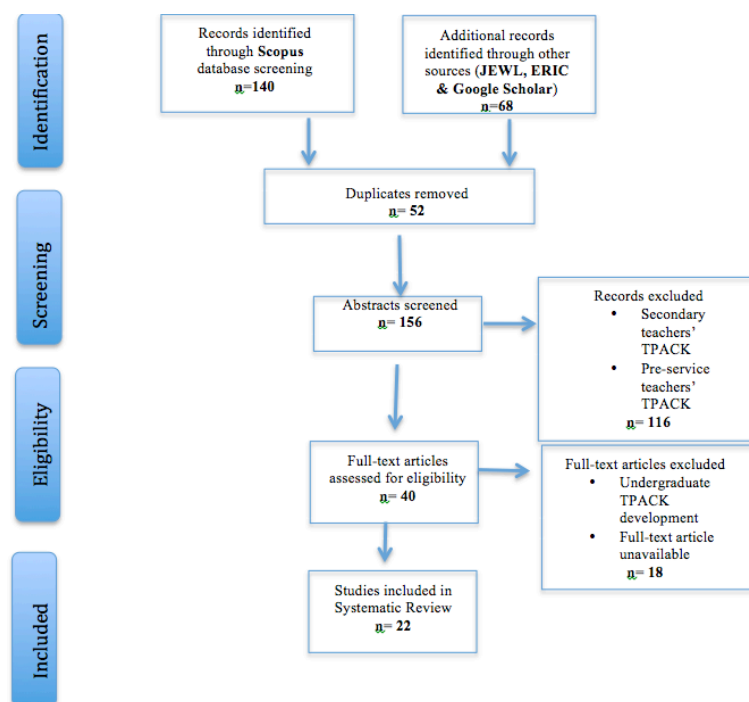
**Methods**

The review followed the inclusion methodology from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) group (Figure 2-2; Adapted from Moher et al., 2009). Two scientific databases were used to create a start sample of articles: Scopus and Education Resources Information Center (ERIC). It is well documented that the TPACK Framework has been in development since 2006 (Mishra and Koehler, 2006), so the review is limited to the articles published between 2006 and December 2020. Only peer-reviewed articles published in scholarly journals were included. Therefore conference proceedings, Ph.D. dissertations, and reports were excluded from the review to ensure only articles that had gone through a rigorous peer-review process were included in the analysis. To explore faculty development of TPACK, the articles had to include at least one of the following search terms: “higher education faculty” AND “technological pedagogical and content knowledge”, OR “TPACK”, OR “TPCK”; and “development of the elements of TPACK”, OR “higher education faculty technological pedagogical and content knowledge development”. The initial search resulted in n= 208 references (140 articles in Scopus, and 68 articles in ERIC). After the initial search, duplicate articles were removed, which left n=156 articles in the sample. All abstracts and keywords of the references were reviewed to ensure each article explicitly looked at the measurement or faculty development of TPACK in higher education. Articles were excluded if they evaluated secondary or pre-service teachers’ TPACK. For example, Nuangchalem (2020) used a case study method to analyze Thai pre-service teachers’ TPACK. Following this analysis of exclusion criteria, n= 40 articles remained in the sample. We had no full-text access to 7 articles so they were also

excluded. This left  $n=33$  articles for full-text screening. In terms of higher education faculty development of TPACK, we specifically looked for strategies used to help faculty understand, know, and communicate concepts using educational technologies. During the full-text screening, if the article was not used to describe higher education faculty development of TPACK, it was not included in this review. For example, Stover (2013) used the TPACK Framework to analyze how a professional development program developed undergraduate students', rather than faculty's, TPACK through an online program, so the study was not included in this review. After the full text screening, twenty-two articles remained for in-depth analysis within this review. (See Figure 2-2)

**Figure 2-2**

*Review Process*



*Note. Adapted from Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) group, Moher D, Liberati A, Tetzlaff J, Altman DG, 2009*

To answer RQ1. How has higher education faculty TPACK been measured and assessed?, we evaluated literature that measured instructors' knowledge to apply TPACK in their classroom by analyzing the instruments and measurement protocols used in each study. To answer RQ2. How do higher education faculty develop their TPACK?, we explored the literature to investigate how researchers designed TPACK professional development and how these interventions impacted instructors' TPACK. An overview of relevant information from the twenty-two studies is found in Appendix A. If the study measured faculty TPACK and or strategies for developing TPACK there is an "x" in the designated column. If the study looked at the development of TPACK in specific subject areas the subject area was written in its designated column as well.

## **Results**

This section will describe the main instruments used to measure and investigate higher education instructors' knowledge to apply TPACK in their classrooms from the reviewed literature. Findings will be organized in the following subcategories of relevant measurement instruments including, surveys, interview protocols, and instructor artifacts.

### **Survey Instruments**

Eleven studies in the reviewed literature presented nine different surveys in which higher education faculty reported their perceived knowledge to apply TPACK or confidence in their TPACK development (See Table 2-1). Reliability and validity data are available in the manuscript for eight of the fifteen survey instruments. Nine of the eleven self-assessment surveys used four to seven-point Likert scales but with various response categories. For example, Jaikaran-Doe & Doe (2015) used a 6-point Likert scale evaluating faculty TPACK confidence with 1-not confident and 6-extremely confident.

In contrast, Nantschev et al. (2020) used a 5-point Likert scale-measuring faculty perceived knowledge to apply TPACK with 1-only rarely true and 5-almost always true. In seven of the studies, the seven knowledge domains of the TPACK Framework were represented in full whereas five studies measured only a subset of the TPACK domains. All eleven studies focused on teaching approaches and technology-related pedagogical competencies and, their relationship to TPACK, but they adapted their surveys from various sources, resulting in different scale usage. The variability between the survey instruments makes it difficult to know which survey is most reliable to measure higher education faculty TPACK.

**Table 2-1**

*Overview of Survey Instruments with Validity and Reliability Evidence*

<b>Authors</b>	<b>Number of Items</b>	<b>Scale</b>	<b>What is measured</b>	<b>Reliability</b>	<b>Validity</b>
Chukkuemeka & Iscioglu (2016)	36	Seven scales- (CK, PK, PCK, TK, TCK, TPK, & TPACK); 7-point Likert scale, strongly disagree-strongly agree	Perception of faculty TPACK level	Cronbach alpha ranged from 0.92-0.96 on seven TPACK constructs	Adapted from Schmidt et al., 2009 Koh et al. (2012)
Cubeles & Riu (2018)	33	Seven scales- (CK, PK, PCK, TK, TCK, TPK, & TPACK); 5-point Likert scale, totally disagree-totally agree	Perception of faculty TPACK level	Cronbach alpha ranged from 0.7-0.94 on seven TPACK constructs	Experts positively rated internal consistency and discriminant validity. Construct analysis
Fabian et al.	12	Three scales-	TPACK	Cronbach's	Adapted

(2019)		(PCK, TCK, TK); 5-point Likert scale	level	alpha values for the whole scale was 0.95	from, Schmidt et al., 2009; Archambault and Barnett (2010)
Faizan et al. (2019)	28	Seven scales-(CK, PK, PCK, TK, TCK, TPK, & TPACK); 5-point Likert scale, strongly disagree-strongly agree	TPACK level	Cronbach's alpha values for the seven constructs ranged from 0.82-0.93	Adapted from Schmidt et al. (2009)
Jaikaran-Doe & Doe (2015)	48	Two scales-(TCK and TPK); 6-point Likert scale, not confident-extremely confident	TPACK confidence	Cronbach's alpha values for the two constructs ranged from 0.7-0.90	Adapted from Jamieson-Proctor et al. (2013)
Morales et al. (2019)	60	Seven scales-(CK, PK, PCK, TK, TCK, TPK, & TPACK)	TPACK confidence	Cronbach alpha ranged from 0.69-0.93 on seven TPACK constructs	Content Validity by a committee of experts. Statistical validity using PAF analysis.
Nantshev et al. (2020)	26	Seven scales-(CK, PK, PCK, TK, TCK, TPK, & TPACK); 5-point Likert scale, only rarely true-almost always true	Perception of TPACK Level	Cronbach alpha ranged from 0.566-0.922 on seven TPACK constructs	Content Validity by five committee experts.
Scott &	40	Seven scales-	Community	Cronbach	Adapted

Nimon (2020)		(CK, PK, PCK, TK, TCK, TPK, & TPACK)	College TPACK Level	alpha ranged from 0.77-0.94 on seven TPACK constructs	from Schmidt et al., 2009 Content Validity by committee experts.
Soomro et al. (2018)	47	Seven scales-(CK, PK, PCK, TK, TCK, TPK, & TPACK); 5-point Likert scale, not all-complete	TPACK Confidence	Cronbach alpha ranged from 0.62-0.90 on seven TPACK constructs	Construct validity, discriminant validity, test-re-test.

Four of the eleven surveys were adapted from Schmidt et al. (2009), which has validation evidence, with exploratory seven-factor analysis and found to be useful in identifying *pre-service teachers'* knowledge to apply TPACK. However, this instrument was created to evaluate the knowledge of primary and secondary pre-service teachers and therefore might have contextual validity with higher education faculty. Adaptations of this survey can be found in Cubeles and Riu's (2018) study that specifically targeted higher education faculty. Cubeles and Riu (2018) decreased the number of items in the areas of technology (TCK, TPK, and TPACK) to increase the number of items about CK and PCK. This decision was made to see if content knowledge affected technology knowledge. Researchers found that faculty PCK was significantly higher than their TK. Scott and Nimon (2020) also administered an adapted version of the Schmidt et al. (2009) survey *The Community College TPACK Survey for Meaningful Learning* survey to adjunct professors and had supporting validity and reliability evidence. However, its

implementation suggested that it would be useful to change the PCK and TK items that had negative and inter-correlations (Scott & Nimon, 2020). Scott and Nimon's (2020) results showed no direct evidence that community college faculty in the study had any formal knowledge or training in pedagogical practices. They suggest the lack of technology training at the community college may explain why some of the TK subscale items show low pattern coefficient, which caused problems with convergent validity and discriminant validity with the TCK subscale (Scott & Nimon, 2020). Even with the above-described survey validation issues, the *Community College TPACK Survey for Meaningful Learning* suggests the seven-knowledge domain structure is a good fit when evaluating TPACK. Scott and Nimon (2020) suggest that TPACK highlights the connections and interactions of the seven domains and should not be evaluated as separate bodies of knowledge.

On the other hand, Fabian et al. (2019) used a three-factor solution (PCK, TCK, and TK) approach adapted from another well-known survey used in Archambault and Barnett (2010), rather than the seven-factor solution used in Schmidt et al. (2009) and related surveys. Fabian et al. (2019) concluded that PCK scores and TK scores were not correlated and not reflective of actual instructional practice. A similar conclusion was reached by the implementation of the Jaikaran-Doe and Doe (2015) survey based on two factors (TCK and TPK) for engineering faculty.

Several of the survey instruments started with Schmidt et al. (2009) original survey, which was designed for primary and secondary pre-service teachers (Chukuuemeka & Iscioglu, 2016; Fabian et al., 2019; Faizan et al., 2019; Scott & Nimon, 2020). Most survey instruments were modified slightly to be more appropriate for the

population of interest and had supporting reliability and validation evidence (See Table 1). Faizan et al. (2019) adapted their survey from Schmidt et al. (2009), and added an open-ended question. The open-ended question evaluated faculty experience in combining content, technology, and teaching approaches at the university level. The rationale was that if the Likert scale items did behave as expected for the target population, qualitative open-ended questions could help identify issues of validity (Faizan et al., 2019).

Two of the adapted survey instruments were somewhat questionable, one did not ask about faculty experiences integrating technology (Chukueemeka & Iscioglu, 2016) and one survey did not test for reliability or validity (Sjöberg & Lilja, 2019). To ensure ecological validity, TPACK survey instruments need to be developed specifically for higher education faculty to capture their experiences with specific content and educational technologies only taught at the collegiate level.

Other surveys looked at different representations of the TPACK Framework to measure faculty TPACK. For example, Amhag et al. (2019) looked at specific digital tools and digital competence related to TPACK through an open-ended survey, and Marcelo and Yot-Dominguez (2019) used the *Inventory of Learning Activities with Technologies* survey. Both of these instruments focused on identifying different types of learning activities using technologies. Furthermore, Fernandes et al. (2020) developed a survey based on the TPACK domains and Work Motivation variables (i.e., intrinsic and extrinsic motivation), intending to identify patterns between the two Frameworks. These studies highlighted the effective use of open-ended surveys to understand the intersection of PCK and TK (Amhag et al., 2019; Marcelo & Yot Dominguez, 2019). Studies also

suggest a need for student opinion in regards to technology integration in higher education classrooms (Amhag et al., 2019; Marcelo & Yot Dominguez, 2019).

Limitations for TPACK domains measured by survey instruments have been reported as statistically variable. For example, TK and PCK showed no correlation with the other TPACK domains (Fabian et al., 2019; Jaikaran-Doe & Doe, 2015; Morales et al., 2019; Scott & Nimon, 2020). This problem in the surveys could be a result of the uncertainty of participants about the construct validity of TPACK as described earlier. There was also a differentiation between survey items for example confidence items vs. knowledge items. Results have shown that faculty confidence in their TPACK increases technology integration (Jaikaran-Doe & Doe 2015; Marcelo & Yot-Dominquez 2019; Soomro et al. 2018), but does confidence in TPACK increase faculty knowledge of technology integration. Some researchers would argue that faculty knowledge and confidence in that knowledge are closely connected (Jaikaran-Doe & Doe 2015; Marcelo & Yot-Dominguez). This connection is important when thinking about how knowledge of TPACK can affect technology integration confidence (Jaikaran-Doe & Doe 2015; Marcelo & Yot-Dominguez, 2019).

In the following sections, I will describe other ways researchers measured and assessed higher education faculty knowledge of TPACK. The reviewed literature also used performance observations, interviews, and data analysis to measure higher education faculty knowledge of TPACK.

### *Interview Protocols*

Two studies from the reviewed literature measured TPACK using interview protocols (Benson & Ward, 2013; Nantshev et al., 2020). Benson and Ward (2013) used

semi-structured interviews to record the ways online faculty integrate new technologies into pedagogical practices. Nantschev et al. (2020) used interviews to assess the use of technology and technology infrastructure in a pre-service mathematics methods course. Both studies used thematic coding based on the three major TPACK knowledge domains to analyze the interview data (CK, PK, and TK).

Nantschev et al. (2020) results suggested that support is needed to address the interaction of TK, PK, and CK. Interviews afforded faculty the opportunity to talk about their experiences using technology in the classroom and their perception of their TPACK development (Nantschev et al., 2020). Recommendations from the interviews suggest faculty need more time and opportunities to be trained to use technology in their teaching practice successfully (Benson & Ward, 2013). Limitations of using semi-structured interviews can be that perspectives from a small group of faculty members (n=3) cannot be statistically generalized to the population (Benson and Ward, 2013; Nantschev et al., 2020). Additional data is needed to support findings such as classroom observations or reflective journals to aid in the triangulation of the findings (Benson & Ward, 2013; Nantschev et al., 2020).

### *Instructor Artifacts*

Three studies used content analysis techniques to evaluate instructor design products (Benson & Ward, 2013; Kohlbacher, 2006; Ouyang & Scharber, 2018). Ouyang and Scharber (2018) used content analysis adapted from Kohlbacher (2006) to assess one online instructor's teaching material. The design products evaluated were the course syllabus, the weekly class agendas, the instructor and student discussion posts, and transcripts of posted instructor videos. Deductive and inductive content analysis was used

to identify representations of the TPACK Framework domains within the artifacts listed above. The study reported that the participant had a high level of TPACK development over the duration of teaching the online course. Findings suggest evaluation criteria can be used to thoroughly assess faculty TPACK development and support online pedagogy development by providing detailed descriptions of what exemplar representations of TPACK are in an online context (Ouyang & Scharber, 2018).

On the other hand, Benson and Ward (2013) used content analysis, in addition to discourse analysis, and focused on online instructors' syllabi, newsfeed, instructional modules, and discussion board posts as sources of data. The authors noted instances of the three broad knowledge domains in TPACK when evaluating the product design. For example, the "alignment of instructional materials with professional standards" was evidence of an instructor's CK (Benson & Ward, p. 159). Findings indicate that when an instructor is not knowledgeable of different technology, they did not have high knowledge of TPACK. However, when an instructor had strong PK, they also had high knowledge of TPACK and increased technology integration (Benson & Ward, 2013).

Many of the selected studies explored how to measure higher education faculty TPACK development through a variety of instruments. However, only a few studies explicitly described each instrument they used, and how they directly measured TPACK development of higher education faculty (Nantshev et al., 2020; Scott & Nimon, 2020; Soomro et al., 2018). An instrument that was not used in the reviewed studies was an observation protocol. Marcelo and Yot-Dominguez (2019) suggest conducting classroom observations to observe in-class interactions of technology integration and receive student feedback. Classroom observations can help inform faculty of their teaching practice by

providing feedback and allowing them to reflect on their observation. Multiple observations can be beneficial when measuring faculty TPACK because it is a source of data that is not self-reported. Self-reported data can be affected by the deviation between the self-reported data (i.e., survey) and the “true” latent construct (Althubaiti, 2016). A “test” similar to a concept inventory could be designed to measure instructors’ level of TPACK knowledge by looking at knowledge vs. confidence. Observation is one data source that can support self-reported data by increasing the validity of evidence through data triangulation. Future studies should look at triangulation of data, to validate results, increase credibility and gain a more detailed understanding of faculty TPACK development to support future researchers in the field (Marcelo & Yot-Dominguez, 2019; Nantshev et al., 2020).

### **TPACK Development**

We also looked for pedagogical techniques and faculty knowledge of how technology can help develop students’ learning. The most common form of faculty TPACK development was through formal professional development programs. Eight articles in the reviewed literature discussed the development of faculty TPACK through formal professional development interventions. Interestingly, these studies emphasize the hypothesized close link between TK and PCK but were unable to establish this link in their data. Faculty participants in the studies viewed TK and PCK as two important domains in the TPACK Framework but found it difficult to articulate how to leverage these knowledge domains to enact technology-enhanced instruction in their classrooms.

Findings will be organized in the following subcategories aligned with the relevant type of professional development models used: lesson or curriculum redesign, one-to-one consultations, and co-teaching.

### *Redesign*

One of the most common forms of professional development is the “redesign model”. The redesigned model is described as a reorganization of an instructor’s lesson that applies their knowledge about the TPACK Framework (Faizan et al. 2019; Rienties et al., 2013). Three studies focused on faculty TPACK development through the redesigned model (Brinkley-Etzkorn, 2018; Faizan et al., 2019; Rienties et al., 2013). Rienties et al. (2013) and Faizan et al. (2019) pointed out the value of faculty working in peer groups to critically re-evaluate their teaching practices and redesign online learning modules to fit their disciplinary classrooms. Similarly, Brinkley-Etzkorn’s (2018) redesign model focused on assisting instructors in implementing best teaching practices and innovative uses of technology in an online classroom setting. Peer reflection was a major component of this particular redesign model and successfully increased faculty technology integration (Brinkley–Etzkorn, 2018; Rienties et al., 2013). There was significant growth and development in faculty TPACK confidence and abilities to integrate technology but not significant growth in faculty perceived knowledge to apply their TPACK (Brinkley-Etzkorn, 2018; Rienties et al., 2013). The authors found adequate training and staff support are necessary to increase instructor awareness of their own TPACK (Rienties et al., 2013). Brinkley-Etzkorn (2018) went a step further and assessed faculty TPACK development based on students’ perspectives of their professor’s ability

to apply their TPACK in practice. Student evaluations of faculty teaching effectiveness pre- and post-redesign training did not change.

In contrast, Faizan et al. (2019) research found that postdoctoral lecturers/researchers developed higher levels of TPACK than full-time and associate professors. The authors explain the findings by suggesting prior knowledge of technology skills-sets is important to help develop effective and appropriate pedagogical approaches during the redesign model process. In line with Brinkley-Etzkorn (2018) Faizan et al. (2019) recommend the importance of understanding faculty prior knowledge before engaging in the redesign process.

#### *One-to-One Consultations*

In contrast to the above studies, Koh (2020) took a slightly different approach to structure professional development to impact TPACK development. For technology-enhanced learning functions, they used one-on-one instructional consultations where an educational consultant from the teaching and learning center conducted 1-hour sessions. The one-on-one consultation provided lesson exemplars and informal conversations to support explorative lesson designs. The study found that if faculty members are supported when using technology modeling their confidence of their TPACK and technology integration in their classroom are both increased (Koh, 2020). Koh (2020) had similar outcomes to Brinkley-Etzkorn (2018) and Rienties et al. (2013) showing an increase in faculty confidence in their TPACK but not their perceived ability to enact practices related to TPACK in their classrooms.

#### *Co-teaching*

Foulger et al. (2015) created technology-infused courses and implemented a

technology-infused professional development to support the course for faculty. The professional development consisted of workshops, individual consultations, modeling, and co-teaching experiences. Results suggested faculty confidence with technology infusion increased but faculty needed additional training to enhance their perceived knowledge related to their TPACK. Another significant aspect of faculty TPACK development was the social interaction component of the professional development designs (Koh, 2020; Faizan et al., 2019; Rienties et al, 2013). Dysart and Weckerle (2015) redesign the professional development model draws from two additional training practices peer-coaching and communities of practice. Peer-coaching bridges teaching with technology and new technology implementation in the classroom through learning by design to reinforce the pedagogy when implementing technology. The community of practice idea provides a platform for faculty to share their technology integration experiences with others and gain feedback. Dysart and Weckerle (2015) suggest this model improved faculty confidence using technology because the professional development was continuous and interactive. The social interaction helped faculty increase their technology integration confidence; however, it did not help develop or increase faculty perceived knowledge of their TPACK (Dysart & Weckerle, 2015).

The reviewed literature revealed an absence of full pedagogical and technological knowledge integration in faculty teaching practices (Brinkley-Etzkorn, 2018; Espinoza & Neal, 2018; Faizan, et al., 2019). Some factors contributed to the disconnection between pedagogical and technological knowledge, which included professional developments that addressed the types of knowledge separately, and professional developments that did not emphasize the importance of their integration.

There was also a lack of approaches to technology and pedagogy integration in faculty-specific disciplines, creating generalized workshops and not content-specific (Brinkley-Etzkorn, 2018; Dysart & Weckerle, 2015; Faizan et al., 2019). Self-reported measures (e.g., survey) were used to evaluate the faculty overall experience with the professional development (Brinkley-Etzkorn, 2018; Faizan et al., 2019; Rienties et al., 2013; Wu, 2016). Another topic that emerged from faculty experiences was that the professional development design structure did not always effectively support faculty in specific disciplinary content areas (Brinkley-Etzkorn, 2018; Faizan et al., 2019). There is also the issue of perceived and actual knowledge of the TPACK framework. This calls for further research to better understand useful approaches for effectively developing a technology-enhanced curricula and supporting faculty TPACK beyond a single event (Dysart & Weckerle 2015; Koh, 2020; Rienties et al., 2013).

## **Discussion**

This literature review set out to answer the following research questions: 1. How has higher education faculty TPACK been measured and assessed? 2. How do higher education faculty develop their TPACK? as a response to the changing role of technology in educational practices. This review shows that as technology integration increases, confidence in an instructor's TPACK increases. Because teacher knowledge and confidence are closely connected (Gess-Newsome, 2015), Marcelo and Yot-Dominguez (2019) argued that it is not enough to only define faculty knowledge but to also study how educational technology is integrated into the classroom. Based on this, we would argue that it is necessary to understand how faculty technology integration levels affect their pedagogical decision-making while using educational technology in the classroom

and how that interacts with their TPACK.

### *Measuring TPACK*

Present evidence shows that practical measurement for higher education faculty calls for further reflection on TPACK as a Framework and how it relates to content-specific higher education faculty (Fabian et al., 2019; Jaikaran-Doe & Doe, P., 2015; Morales et al., 2019; Scott & Nimon, 2020). Researchers need to pay close attention to the three main domains of TPACK (technology, content, and pedagogy) and the intersection sub-domains (Brinkley-Etzkorn, 2018; Dysart & Weckerle, 2015; Faizan et al., 2019).

This review revealed that the link between TK and PCK was difficult to measure during professional development studies because the faculty did not think PCK and TK were related to one another and therefore were unable to make connections between the two even after the intervention (Benson & Ward, 2013; Brinkley-Etzkorn, 2018; Wu, 2016). There is a need to understand how to better foster the link between the development of TK and PCK domains in faculty through formal professional development interventions. This need could be met by merging a team of experts that are knowledgeable in technology, content, and pedagogy who would lead the professional developments.

There were a variety of methods and approaches used to measure higher education faculty TPACK development in the literature, which makes it difficult to compare the reliability of the outcomes because most of the studies did not use mixed methods. Data generalization is a major challenge for research on TPACK, which calls for more validated qualitative and quantitative instruments in the specific content areas to

understand TPACK development (Benson & Ward, 2013; Nantshev et al., 2020; Ouyang & Scharber, 2018). It would be helpful to understand what knowledge base is necessary for specific subject domains to closely assess knowledge of faculty TPACK (Fernandes et al., 2019). Additionally, a triangulation of data (observations, interviews, and science-specific survey) should be used to validate sub-discipline faculty TPACK. This can contribute to professional development opportunities and assessment instruments that can be used to support the evaluation of sub-discipline faculty TPACK development across higher education institutions (Marcelo & Yot-Dominguez, 2019; Nantshev et al., 2020).

#### *Assisting Faculty in Developing TPACK*

From research on pre-service teacher development (e.g., Drummond & Sweeney, 2013; Voogt et al., 2012), we know that collaborative redesign models and representation of technology-infused curriculum are promising strategies to develop knowledge of instructor TPACK. Redesign models allow faculty to think about appropriate educational technologies to potentially integrate into their lesson; address concerns with educational technology comfort levels, and potentially increase faculty technology integration confidence. This review found that faculty got experience in the redesign of technology-infused lessons and increased their confidence in their TPACK, but did not increase their knowledge to enact that TPACK in their classroom practice (Brinkley-Etz Korn, 2018; Faizan et al., 2019; Rienties et al., 2013).

In higher education, there are many disciplines and sub-disciplines that require specific content and technological knowledge (Cubules & Riu, 2018; Jaikaran-Doe & Doe, 2015; Morales et al., 2019). Dysart and Weckerle (2015) recommend faculty

connect with expert technology curriculum instructors in their discipline to support their integration of technology. Additionally, a technology expert that targets specific disciplines and sub-disciplines could increase faculty knowledge of TPACK within their discipline or sub-discipline.

### **Conclusion and Areas for Future Research**

Based on the results of this study, we can conclude that there is a lack of studies on discipline-specific TPACK development in higher education. This calls for further research to better understand useful approaches to effectively create and integrate technology-enhanced discipline-specific curriculum, to better support faculty TPACK development. We recommend the following directions for future research on the development of knowledge of the TPACK Framework in higher education faculty. First, future research should more thoroughly investigate broad subject disciplines, for instance, science. We suggest focusing on science specifically because it constitutes an advantaged subject matter that encompasses a lot of sub-disciplines when considering technology integration. There are efficient educational environments and applications available for science faculty (e.g., simulations and modeling tools, computer-based laboratories, and Web resources), which offer a great variety of affordances for both students and faculty (Tan et al., 2012). Researchers have advocated for technology integration in science (Harris et al., 2017; Jimoyiannis & Komis, 2001; Lee et al., 2011; Webb, 2005), but have not done many investigations to study the interaction between technology-integration level and faculty TPACK.

Secondly, further research needs to focus on the complex relationship between TPACK (teacher knowledge), practice (what they do in the classroom), and teacher

confidence in technology (Dysart & Weckerle 2015; Koh, 2020; Rienties et al., 2013). This can allow a closer look at discipline-based higher education faculty TPACK to better target the developmental needs of instructors' differing levels of technology integration. Comparisons of faculty in different sub-disciplines (e.g., biology, geometry, physics) can be made in professional development design. Such studies can allow deeper insights into how TPACK can be modeled and developed in different sub-discipline professional development, align technology training with a specific teaching strategy, and provide context and examples of how technology can be used for their respective sub-discipline areas.

### References

- Abrams, E., Southerland, S. A., & Evans, C. (Eds.). (2008). Integrating inquiry in the classroom: Identifying necessary components of a useful definition. Age of Information Press.
- Amhag, L., Hellström, L., & Stigmar, M. (2019). Teacher educators' use of digital tools and needs for digital competence in higher education. *Journal of Digital Learning in Teacher Education*, 35(4), 203-220. <https://doi.org/10.1080/21532974.2019>
- Angeli, C., & Valanides, N. (2009). Epistemological and methodological issues for the conceptualization, development, and assessment of ICT-TPCK: Advances in technological pedagogical content knowledge. *Computers & Education*, 52, 154168. <https://doi:10.1016/j.compedu.2008.07.006>
- Anwaruddin, S. (2015). ICTs in language and literacy education in Bangladesh: A critical review. *Current Issues in Education*, 18(1), 1-12.
- Archambault, L., Barnett, J. (2010). Revisiting technological pedagogical content knowledge: Exploring the TPACK framework. *Computers and Education*, 55(4).

- Benson, S., & Ward, C. (2013). Teaching with technology: Using TPACK to understand teaching expertise in online higher education. *Journal of Education Computing Research*, 48(2), 153-172.
- Blonder, R. Jonatan, M., Bar-Dov, Z., Benny, N., Rap, S. & Sakhnini, S. (2013). Can you tube it? Providing chemistry teachers with technological tools and enhancing their self-efficacy beliefs. *Chemistry Education Research and Practice*, (3).  
<https://doi.org/10.1039/D0RP00291G>
- Brinkley- Etzkorn, K. (2018). Learning to teach online: Measuring the influence of faculty development training on teaching effectiveness through a TPACK lens. *The Internet and Higher Education*, 38, 28-35.  
<https://doi.org/10.1016/j.iheduc.2018.04.004>
- Cavanagh, R., Koehler, M. (2013). A turn toward specifying validity criteria in the measurement of technological pedagogical content knowledge (TPACK). *Journal of Research on Technology in Education*, 46(2).
- Chai, C. (2019). Teacher professional development for science, technology, engineering and mathematics (STEM) education: A review from the perspectives of technological pedagogical content (TPACK). *Asia-Pacific Education Research*, 28(1), 5-13. <https://doi.org/10.1007/s40299-018-0400-7>
- Chai, C., Koh, J., & Tsai, C. (2013). A review of technological pedagogical content knowledge. *Educational Technology & Society*, 16(2), 31–51.
- Chukwuemeka, E., & Iscioglu, E. (2016). An examination of lecturers' technological pedagogical content knowledge perceptions at the faculty of education in emu in Cyprus. *Croatian Journal of Education*, 18(4), 999-1034.  
<https://doi.org/10.15516/cje.v18i4.1845>
- Cubeles, A., & Riu, D. (2018). The effective integration of ICTs in universities: the role of knowledge and academic experience of professors. *Technology, Pedagogy and Education*, 27(3), 339-349. <https://doi.org/10.1080/1475939X.2018.1457978>
- Depape, F., Verschaffel, L., & Kelchtermans, G. (2013). Pedagogical content knowledge: A systematic review of the way in which the concept has pervaded mathematics educational research. *Teaching and Teacher Education*, 34, 12-25.  
<https://doi.org/10.1016/j.tate.2013.03.001>
- Drummond, A., & Sweeney, T. (2017). Can an objective measure of technological pedagogical content knowledge (TPACK) supplement existing TPACK measures? *British Journal of Educational Technology*, 48(4), 928-939.
- Dysart, S., & Weckerle, C. (2015). Professional development in higher education: A model for meaningful technology integration. *Journal of Information Technology Education: Innovations in Practice*, (14), 255-265.
- Ertmer, P. A., & Ottenbreit-Leftwich, A. T. (2010). Teacher technology change: How knowledge, confidence, beliefs, and culture intersect. *Journal of Research on Technology in Education*, 42(3), 255-284.
- Espinoza, B. D., & Neal, M. (2018). Incorporating contextual knowledge in faculty professional development for online teaching. *Journal on Centers for Teaching and Learning*, 10, 24-44.

- Fabian, K., Clayes, E., & Kelly, L. (2019). Putting design into practice: An investigation of TPACK scores of lecturers in a networked institution. *Research in Learning Technology*, 27.
- Faizan, N., Gottlieb, M., Löffler, A., Utesch, M., Krcmar, H. (2019). State-of-the-art to measure the TPACK level of trainees in higher education to increase the learnability of the train-the-trainer (TTT) sessions. *IEEE XPlore*, 384-391.
- Fernandes, S., & Gupta, P. (2019). Relationship between work motivation scale and TPACK. *Journal of Applied Research in Higher Education*, 12(4), 693-708.
- Foulger, T., Buss, R., Wetzel, K., & Lindsey, L. (2015). Instructors' growth in TPACK Teaching technology-Infused methods courses to pre-service teachers. *Journal of Digital Learning in Teacher Education*, 31(4), 134-147.  
<https://doi.org/10.1080/21532974.2015.1055010>
- Grajek, S., & Rotman, D. (2014). Top-Ten IT Issues, 2014: Be the Change You See. *Educause Review*, 49(2), 10.
- Gess-Newsome, J. (2015). *Re-examining pedagogical content knowledge in science education* (A. Berry, P. Friedrichsen, & J. Loughran, Eds.) Routledge.
- Graham, C. (2011). Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). *Computers and Education*, 57(3).
- Graham, C., Burgoyne, N., Cantrell, P., Smith, L., Clair, L., and Harris, R. (2009). TPACK development in science teaching: Measuring the TPACK confidence of in-service science teachers. *Tech-Trends*, 53(5), 70-79.
- Griffen, L., Dodds, P., & Rovegno, I. (2013). Pedagogical content knowledge for teachers: Integrate everything you know to help students learn. *Journal of Physical Education and Dance*, 67(9), 58-61.
- Guerriero, S. (2017). *Pedagogical Knowledge and the Changing Nature of the Teaching*. (Ed.) OECD Publishing.
- Guzey, S., & Roehrig, G. (2009). Teaching science with technology: Case studies of science teachers' development of technology, pedagogy, and content knowledge. *Contemporary Issues in Technology and Teacher Education*, 12(2).
- Harris, J., Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, 9(1), 60-70.
- Harris, J., Phillips, M., Koehler, M., Rosenberg, J. (2017). TPCK/TPACK research and development: Past, present, and future directions. *Australasian Journal of Educational Technology*, 33(3).
- Hickey, D., Kindfield, A., Horwitz, P., & Christie, M. (2003). Integrating curriculum, instruction, assessment, and evaluation in a technology-supported genetics learning environment. *American Educational Research Journal*, 40(2), 495-538.
- Jaikaran-Doe, S., & Doe, P. (2015). Assessing technological pedagogical content knowledge of engineering academics in an Australian regional university. *Australia Asian Journal of Engineering Education*, 20(2), 157-167.  
<https://doi.org/10.1080/22054952.2015.1133515>
- Jang, S., & Chen, K. (2010). From PCK to TPACK: Developing a transformative model for pre-service science teachers. *Journal of Science Education and Technology*, 19(6), 553-564. <https://doi.org/10.1007/s10956-010-9222-y>

- Janssen, N., Lazonder, A. (2015). Implementing innovative technologies through lesson plans: What kind of support do teachers prefer? *Journal of Science Education Technology*, (24), 910–920. <https://doi.org/10.1007/s10956-015-9573-5>
- Jenkinson, J., McGill, G. (2012). Visualizing protein interactions and dynamics: Evolving a visual language for molecular animation. *CBE—Life Sciences Education*, (11), 103–110.
- Jose, M., Bonete, G., Jensen, M., Katona, G. (2018). A practical guide to developing virtual and augmented reality exercises for teaching structural biology. *Biochemistry and Molecular Biology Education*, 47(1), 16–24.
- Kara, Y. (2018). Determining the effects of microscope simulation on achievement, ability, reports, and opinions about microscope in general biology laboratory course. *Universal Journal of Educational Research*, 6(9), 1981-1990. <https://doi.org/10.13189/ujer.2018.060917>
- Kiray, S. (2016). Development of a TPACK self-efficacy scale for preservice science teachers. *International Journal of Research in Education and Science (IJRES)*, 2(2), 527- 541.
- Koehler, M., Mishra, P. (2008). Handbook of Technological Pedagogical Content Knowledge (TPCK) for Educators. (AACTE Committee on Innovation and Technology, Ed.). Routledge.
- Koehler, M. & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, 9(1), 60-70.
- Koehler, M., Mishra, P., Kereluik, K., Shin, T., & Graham, C. (2014). Handbook of Research on Educational Communications and Technology. (J.M. Spector et al. Eds.)(4<sup>th</sup> edition). Springer Science + Business Media.
- Koh, J. (2020). Three approaches for supporting faculty technological pedagogical content knowledge (TPACK) creation through instructional consultation. *British Journal of Educational Technology*, 51(6), 2529-2543. <https://doi.org/10.1111/bjet.12930>
- Koh, J., Chai, C., Benjamin, W., Hong, H. (2015). Technological pedagogical content knowledge (TPACK) and design thinking: A framework to support ICT lesson design for 21st century learning. *Asia-Pacific Education Researcher*, 24(3).
- Lin, T., Tsai, C., Chai, C. (2013). Identifying science teachers' perceptions of technological pedagogical and content knowledge (TPACK). *Journal Science Education Technology*, (22), 325–336. <https://doi.org/10.1007/s10956-012-93966>
- Lee, H, Tsai, H, Yu, H. (2008). Developing the digital content industry in Taiwan. *Review of Policy Research*, 25(2).
- Levesque, A. (2011). Using clickers to facilitate development of problem-solving skills. *CBE— Life Sciences Education*, 10, 406–417. <https://doi.org/10.1145/3337682.333770>
- Lim, C. P., Zhao, Y., Tondeur, J., Chai, C., and Tsai, C. (2013). Bridging the gap: Technology trends and use of technology in schools. *Educational Technology & Society*, 16(2), 59– 68.
- Marcelo, C., & Yot-Domínguez, C. (2019) From chalk to keyboard in higher education classrooms: Changes and coherence when integrating technological knowledge

- into pedagogical content knowledge. *Journal of Further and Higher Education*, 43(7), 975-988. <https://doi.org/10.1080/0309877X.2018.1429584>
- Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009 Jul 21;6(7):e1000097. doi: 10.1371/journal.pmed.1000097. Epub 2009 Jul 21. PMID: 19621072; PMCID: PMC2707599.
- Morales, M., Anito, J., Avilla, R., Abulon, E., & Palisoc, C. (2019). Proficiency indicators for philippine STEAM (science, technology, engineering, agri/fisheries, mathematics) educators. *Philippine Journal of Science*, 148(2), 263-275.
- Nantschev, R., Feuerstein, E., González, R., Alonso, I., Hackl, W., Petridis, K., Triantafyllou, E., & Ammenwerth, E. (2020). Teaching approaches and educational technologies in teaching mathematics in higher education. *Education Sciences*, 10(354). <https://doi.org/10.3390/educsci10120354>
- National Research Council. (2012). *Improving Measurement of Productivity in Higher Education*. The National Academies Press. <https://doi.org/10.17226/13117>
- Nuangchalerm, P. (2020). TPACK in ASEAN perspectives: Case study on Thai pre-service teacher. *International Journal of Evaluation and Research in Education*, 9(4), 993-999. <https://doi.org/10.11591/ijere.v9i4.20700>
- Ouyang, F., & Scharber, C. (2018). Adapting the tpack framework for online teaching within higher education. *International Journal of Online Pedagogy and Course Design*, 8(1).
- P21, Partnership for 21st Century Learning (2016). P21 Framework Definitions. Retrieved from <http://www.p21.org/our-work/resources/for-educators>.
- Pedrosa-de-Jesus, H., Moreira, A., Lopes, B., & Watts, D. (2014). So much more than just a list: Exploring the nature of critical questioning in undergraduate sciences. *Research in Science and Technological Education*, 32(2).
- Petto, A. (2019). Technology meets pedagogy: Comparing classroom response systems. *Research and Teaching*, 48(4).
- Reddy, M. & Mint, P. (2017). Impact of simulation based education on biology student's academic achievement in DNA replication. *Journal of Education and Practice*, 8(15).
- Rienties, B., Brouwer, N., Carbonell, K., Townsend, D., Rozendal, A., van der Loo, J., Dekker, P., & Lygo-Baker, S. (2013). Online training of TPACK skills of higher education scholars: a cross-institutional impact study. *European Journal of Teacher Education*, 36(4), 480-495. <https://dx.doi.org/10.1080/02619768.2013.801073>
- Schmid, M., Brianza, E., Petko, D. (2020). Developing a short assessment instrument for Technological Pedagogical Content Knowledge (TPACK.xs) and comparing the factor structure of an integrative and a transformative model, *Computers Education*, 157. <https://doi.org/10.1016/j.compedu.2020.103967>.
- Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological pedagogical content knowledge (TPACK): The development and validation of an assessment instrument for preservice teachers. *Journal of Research on Technology in Education*, 42(2), 123-149.

- Scott, K., & Nimon, K. (2020) Construct validity of data from a tpack self-assessment instrument in 2-year public college faculty in the United States, *Journal of Research on Technology in Education*.  
<https://doi.org/10.1080/15391523.2020.1790444>
- Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(1), 4-14.
- Sjöberg, J., Lilja, P. (2019). University teachers' ambivalence about the digital transformation of higher education. *International Journal of Learning, Teaching and Educational Research*, 18(13), 133-149.  
<https://doi.org/10.26803/ijlter.18.13.7>
- Sobel, K., & Grotti, M. (2013). Using the TPACK framework to facilitate decision-making on instructional technologies. *Journal of Electronic Resources Librarianship*, 25(4).
- Soomro, S., Bhatti, T., Soomro, A., Basir, N., Ali, N., & Gill, N. (2018). TPACK adaptation among faculty members of education and ICT departments in university of sindh, Pakistan. *International Journal of Advanced Computer Science and Applications*, 9(5).
- Tafli, T. (2019). Pre-service teachers' views about the importance of technology in science teaching: A case study in biology education. *Euromentor Journal*, 10(4), 32-44.
- Tan, T., Lin, M., Chu, Y., & Liu, T. (2012). Educational affordances of a ubiquitous learning environment in a natural science course. *Journal of Educational Technology & Society*, 15(2), 206- 219.
- Tsai, H. (2015). A senior teacher's implementation of technology integration. *International Education Studies*, 8(6).
- Voogt, J., Fisser, P., Roblin, N., ParejaTondeur, J., & van Braak, J. (2013). Technological pedagogical content knowledge—A review of the literature. *Journal of Computer Assisted Learning*, 29(2), 109-121.
- Voogt, J., Fisser, P., Tondeur, J., & van Braak, J. (2016). *Using theoretical perspectives in developing an understanding of TPACK*. (M. C. Herring, M. J. Koehler, & P. Mishra Eds.). Routledge.
- Wahnono, B., & Chang, C. (2019). Development and validation of a survey instrument (aka) towards attitude, knowledge and application of STEM. *Journal of Baltic Science Education*, 18(1), 63-76. <https://doi.org/10.33225/jbse/19.18.63>
- Wilkin, C. L., Rubino, C., Zell, D., & Shelton, L. M. (2013). Where technologies collide: A technology integration model. *Cutting Edge Technologies in Higher Education*, 6, 1701–1711. <https://doi.org/10.1108/S2044-9968>
- Willermark, S. (2018). Technological Pedagogical and Content Knowledge: A Review of Empirical Studies Published From 2011 to 2016. *Journal of Educational Computing Research*, 56(3).
- Wu, Y. (2013). Research trends in technological pedagogical content knowledge (TPACK) research: A review of empirical studies published in selected journals from 2002 to 2011. *British Journal of Educational Technology*, 44(3), 73–76. <https://doi.org/10.1111/j.1467-8535.2012.01349>

- Wu, B., Hu, Y., Gu, X., & Lim, C. (2016). Professional development of new higher education teachers with information and communication technology in shanghai: A kirkpatrick's evaluation approach. *Journal of Educational Computing Research*, 54(4), 531–562
- Yeh, Y., Hsu, Y., Wu, H., Hwang, F., & Lin, T. (2014). Developing and validating technological pedagogical content knowledge-practical (TPACK-practical) through the Delphi survey technique. *British Journal of Educational Technology*, 45(4), 707–722. <https://doi.org/10.1111/bjet.12078>
- Yeh, Y., Hsu, Y., Wu, H., & Chien, S. (2017). Exploring the structure of TPACK with video- embedded and discipline-focused assessments. *Computers & Education*, 104(49), 64.
- Yilmaz, Y., Lal, S., Tong, X. C., Howard, M., Bal, S., Bayer, I., Monteiro, S., & Chan, T. M. (2020). Technology-Enhanced Faculty Development: Future Trends and Possibilities for Health Sciences Education. *Medical science educator*, 30(4), 1–10. Advance online publication. <https://doi.org/10.1007/s40670-020-01100-1>
- Young, J., Young, J., & Hamilton, C. (2013). The use of confidence intervals as a meta-analytic lens to summarize the effects of teacher education technology courses on pre-service teacher TPACK. *Journal of Research on Technology in Education*, 46(2).
- Young, J., Young, J., & Shaker, Z. (2012). Technological pedagogical content knowledge (TPACK) literature using confidence intervals. *Tech Trends*, 56(5).
- Yurdakul, K. (2018). Modeling the relationship between pre-service teachers' tpack and digital nativity. *Educational Technology Research and Development*, 66(2), 267–281

### CHAPTER III: STUDY 1

#### **Technological Pedagogical and Content Knowledge Development in Biology Instruction: Measuring Biology Instructors' Technology Integration**

*This manuscript will be submitted to Journal of Science Education and Technology*

#### **Abstract**

Since the beginning of the 21st century, advances in technology have influenced the rapid role of its integration in curriculum and instruction in secondary and post-secondary classrooms. More recently, the rapid shift to online instruction in early March 2020 pushed instructors to transfer their regular face-to-face classes to online in a matter

of weeks. The Technological Pedagogical and Content Knowledge (TPACK) Framework is a critical component for understanding how and why instructors integrate technology in their teaching practices (Mishra & Koehler, 2006). Presently, not much is known about higher education instructors' TPACK and how it impacts technology integration in their classrooms. Through survey analysis with a sample of 90 biology instructors from institutions nationwide, we found that instructors' TPACK in the classroom was high. In general, content-related Likert survey items were scored higher and technology items were scored lower. Biology Graduate Teaching Assistants have higher technology integration levels than the other instructor types (e.g., tenured track faculty). These data indicate a difference between the educational technology integration of particular types of biology instructors. Also, there seems to be a gap between instructors' perception of their knowledge and realized the ability to integrate technology into their instruction. Further research needs to focus on the complex relationship between teacher knowledge and instructional practice.

### **Introduction**

Biology is a discipline that examines and explains the structure, function, development, and classification of living organisms on a macroscopic and microscopic level (Celik et al., 2020). In this discipline, some concepts are abstract to learners because they are not easily visible to the naked eye (i.e., cell model, DNA structure). In addition, some biological structures are not easily visible (i.e., heart, lungs). This makes the biological relationships between the invisible concepts complicated for individuals to learn and also makes teaching biology difficult for many instructors (Celik et al., 2020). However, educational technology can help make abstract concepts and structures visible,

which can then help eliminate common misconceptions in biology and promote student learning (Chen, et al., 2018; Somyürek 2014). Educational technology (i.e. animations, simulation, mobile learning, digital games) has become a foundation in helping to achieve student-learning outcomes in biology classrooms (Johnson & Lester, 2016).

Traditional educational technologies are often categorized by their functional complexity, use over time, and transparency of use (Bruce & Hogan, 1998). Traditional educational technologies have become so common in classrooms that they sometimes cease to be viewed as a technology at all. For example, a pencil is categorized as a traditional educational technology that is used for writing (consistent function), has not changed much over time (temporal stability), and is relatively simple in relation to its function (transparency). More advanced educational technologies, such as computer simulations, animations, and software are categorized as having various uses depending on the context (functional variability), rapidly changing overtime (little temporal stability) and the inner workings are hidden from the user if not trained on the specific educational technology (low transparency) (Mishra & Koehler 2006). The use of educational technologies (e.g., computer simulation, animation, and educational software) provides opportunities for instructors to support student's higher-level thinking skills, and facilitate conceptual change by creating interactive learning environments (Anwaruddin, 2015; Pedrosa-de-Jesus, Moreira, Lopes, & Watts, 2014; Shelly, Gunter & Gunter, 2012). However, depending on their functional complexity, temporal stability, and transparency of use, they may be difficult for instructors to adapt to support learning. Online courses are a learning environment where educational technologies can be used. The section below describes the landscape of online instruction over the past two

decades.

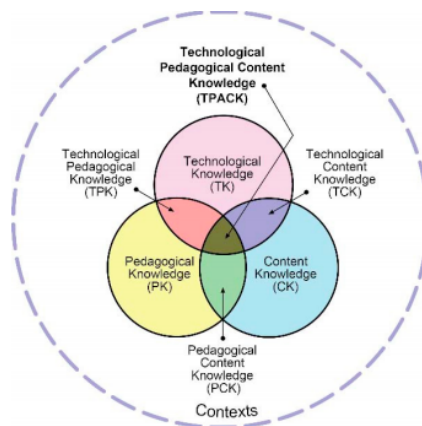
The use of online courses for instruction has shown a steady increase in higher education institutions over the past two decades (Allen & Seaman, 2013; Allen et al., 2015). More recently, the rapid shift to online instruction in early March 2020 pushed many instructors to transfer their regular face-to-face classes to online in a matter of weeks. Therefore, it was necessary to think about how to structure teaching environments that foster the use of innovative educational technologies (Celik et al., 2020; Flogie et al., 2018; Somyürek, 2014). Some predictors of effective integration of educational technology are, the amount of instructor knowledge of the technology, instructor knowledge of the disciplinary content associated with technology, and the instructor knowledge of the instructional strategies to integrate the educational technology and content holistically. This knowledge is collectively known in the literature as technological pedagogical and content knowledge (TPACK) (Mishra & Koehler 2006). Developing technological knowledge and integrating it with content teaching and learning in a specific discipline has brought new challenges to instructors, especially with abstract topics like those found in biology (Celik et al., 2020; Willermark, 2018). Without extant research, the goal of this study was to better understand biology instructors' TPACK in higher education contexts and how that impacts their integration of educational technologies in their classroom teaching practices.

## **Theoretical Framework and Review of Literature**

### *The TPACK Framework*

The TPACK Framework was designed to assist in understanding how and why K-12 teachers integrate educational technology in their classrooms. TPACK builds on Shulman's (1986) original pedagogical content knowledge (PCK) Framework by integrating technology knowledge into it (Mishra & Koehler, 2006; Koehler & Mishra, 2009). The PCK Framework conceptualizes and articulates the integration of teaching knowledge and subject matter knowledge that an instructor needs to be an effective teacher (Niess, 2005). According to Jang and Chen (2010), a teacher with strong PCK can transform pedagogical knowledge and content knowledge into instructional practices that help teachers understand student-learning capabilities and anticipate obstacles in the learning process (Jang & Chen, 2010).

The TPACK Framework highlights three essential components of teacher knowledge: pedagogy, content, and technology knowledge (Chai et al., 2013; Harris et al., 2009; Mishra & Koehler, 2006). The interactions between the three major components of TPACK are pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and technological pedagogical content knowledge (TPACK) (Mishra & Koehler, 2006).

**Figure 3-1***The Seven Components of the TPACK Framework*

*Note.* Adapted from: What is technological pedagogical content knowledge? Koehler, M. & Mishra, P., 2009.

Although individual constructs have been operationalized, there is not a universal consensus on the theoretical scope of PCK and TPACK. The only point on which a consensus has been formed is a theoretical model put forth by Mishra & Koehler (2006) (See Figure 3-1). So while it seems this model is powerful it is likely too simplistic. In the studies conducted after the emergence of this model, researchers have deepened and widened the complexity of these seven components (Kiray, 2016). Today's teachers are growing according to their role in helping students achieve their educational goals through technology (Nasution et al., 2017). In the era of digitization, not only are the students required to develop skills in the technological progress that is increasing daily, but teachers also need to update their knowledge and skills, both in the fields of technology and science (Nasution et al., 2017). The shifting environments around

educational technologies have only continued to highlight where this model needs both improvement and detail. In the following section, we review the literature on how this model has been used in K-12 science settings to provide background on the strengths and limitations of this model in educational research.

### *TPACK Development in K-12 Science Teachers*

Teachers play a vital role in education, designing curriculum, preparing lessons, and technology availability has increased so providing professional development in TPACK is critical. In recent years, technology has had an impact on teaching and learning. Many studies related to TPACK focus on how to teach with educational technology in middle and high school settings. For example, Jang & Chen (2010) study explored four middle school in-service science teachers' use of interactive whiteboards. A TPACK-COIR Model (TPACK Comprehension, Observation, Instruction, and Reflection) was used to evaluate science teachers' TPACK and interactive whiteboard integration into their classroom instruction. This model consisted of four activities, which included TPACK comprehension, peer instruction observation, classroom instruction with interactive whiteboards, and TPACK reflection (Jang & Chen, 2010). Results suggested science teachers' presentations were enhanced through the TPACK-COIR Model as they used the interactive whiteboards as an instructional tool. This demonstrates that the use of TPACK as a framework for professional development can be useful. It also highlights the simplicity of the model in that it must be integrated with other components of instructional best practices for teachers to learn and grow.

Researchers also reported growth in pre-service teacher performance when

considering their work through the TPACK Framework. Jaipal-Jamani & Figg, (2015) also evaluated middle school science teachers (n=3) through a learning workshop. The purpose of the workshops was to develop pre-service science teachers' TPACK as they created and integrated a blog activity in the classroom. Through researchers' field notes, classroom observations, and student artifacts, the results indicate that TPACK was developed through a workshop experience and the application of skills (Jaipal-Jamani & Figg, 2015). Although pre-service science teachers had positive experiences integrating technology in their classrooms, lack of technical support and lack of technology modeling, as a pedagogical strategy in content area teaching was a concern (Jaipal-Jamani & Figg, 2015; Lei, 2009). Jaipal-Jamani & Figg (2015) suggest evaluating science teachers' TPACK before professional development and creating workshops that build teacher knowledge about how to integrate technology in specific content areas. This study demonstrates that the development of TPACK cannot be isolated from disciplinary (Content Knowledge) expertise.

Sheffield & McIlvenny (2014) research focused on pre-service science teachers' technology literacy and inquiry as it related to the TPACK Framework. Using Internet tools (e.g. Scoop.it and Pinterest), results indicated that pre-service teachers believed engaging in online inquiry improved their confidence in technology literacy and inquiry associated with scientific phenomena. Sheffield & McIlvenny (2014) suggested knowing about the latest technology is not enough (Technology Knowledge), but that technology literacy is perhaps more important. Both students and teachers need to be able to engage with educational technologies efficiently and effectively. In line with Sheffield &

McIlvenny (2014), Kiray (2016) believed it is important that teachers have technological, pedagogical, and content knowledge in the science classroom. However, this study took a slightly different approach to instructional professional development by creating an instrument to measure pre-service science teachers' TPACK self-efficacy. The survey included 55 items that highlighted the seven TPACK domains. Results indicated statistically significant differences in self-efficacy between high TPACK and low TPACK groups (n=467). One distinctive feature of the survey instrument was the content knowledge domain. Most TPACK instruments measure content knowledge in general terms, however, the scale developed in this research study was created specifically for disciplinary science knowledge. For example, in this study Kiray's (2016) approach asked questions about life science and social science independently. The instrument investigates physical science, chemistry, biology, earth science, and astronomy as individual disciplinary items related to participant content knowledge. As a result, researchers concluded that their survey instrument included efficient measures of pre-service science teachers' TPACK self-efficacy because it included specific content-related items.

In summary, researchers have shown a growing interest in studying how pre-service and in-service science teachers integrate technology into teaching and developing their TPACK. Studies have demonstrated that teachers need support and a good understanding of how technology can be integrated with pedagogy and content knowledge to effectively implement it into classroom instruction (Jaipal-Jamani & Figg, 2015; Sheffield et al., 2014). There are few content-specific examples of technology

knowledge being developed through professional development and the application of teaching strategies in these disciplines as teachers develop TPACK. Despite its importance, many previous studies have attempted to investigate the development of TPACK without considering the critical disciplinary knowledge component of content knowledge. Concrete examples of scientific topics could help better describe the interaction among all the domains in the TPACK Framework (Bilici et al., 2016; Jang & Chen, 2010). The following section reviews research exploring TPACK development in biological sciences.

#### *TPACK in Biology Disciplinary Contexts*

The utilization of technology in teaching specific content is also described in the literature using TPACK. Most studies using the TPACK Framework in a biology discipline are focused on pre-service teachers and their classroom technology integration practices (Maeng et al., 2013; Srisawasdi et al., 2018). Aquino's (2015) study evaluated biology pre-service teachers enrolled in educational college courses and their TPACK self-efficacy. They asked if TPACK differed by participant demographics (i.e. gender, internet access). A TPACK questionnaire was used to collect data and findings showed participants had good TPACK self-efficacy, but there were statistically significant differences by gender and participants' access to reliable Internet. The researcher suggests reviewing and improving instructional practices and curriculum at the collegiate level to enhance the TPACK of pre-service biology teachers (Aquino, 2015). When it comes to integrating technology in biology classrooms, instructors' technological self-efficacy is an indicator of technology use in their practice. Furthermore, this can help

explain why instructors who are skeptical about educational technologies may not try new technologies.

Other studies investigating biology instructors' TPACK focused on mastery of competence in teaching biology with technology (Irdalisa et al., 2020; Nasution et al., 2017; Putri et al., 2020). According to Irdalisa et al. (2020)- the mastery of TPACK is important for teachers to have quality student learning experiences. The purpose of the study was to evaluate the mastery of TPACK among biology teachers in a teacher certification program. Sixty-eight biology teachers took a 33-item multiple-choice test to investigate TPACK competency in this sample. Results indicated biology teachers' overall mastery of TPACK was categorized as "fair." More specifically, biology teachers have mastered PK and CK, but the TK was found to be in the "poor" category. This is an indication that biology teachers lack the mastery of basic technical knowledge and it is disconnected from their content knowledge further problematizing the TPACK model.

Another study that highlighted biology teachers' TPACK mastery used Content Representation (CoRes) as it relates to the technology integration and pedagogy in teaching biology (Nasution et al., 2017). The CoRes instrument results were the primary data and semi-structured interviews were used as supporting data. A CoRes scoring rubric was used with coding 1- 3 that categorized participants into upper, middle, or lower TPACK groups. The results showed that biology teachers were in the lower and middle category for mastery of Content Representation as it relates to technology integration and pedagogy using educational technologies. The findings suggest the ability of biology teachers to determine the essential concepts in the CoRes is inadequate and

needs to be further improved (Nasution et al., 2017). Similarly, Putri et al. (2020) evaluated biology teachers' TPACK competence using CoRes, but looked at a specific content topic, the classification of living things. The study participants were in-service biology teachers and data were collected through a CoRes questionnaire that focused on their competency of classifying living things while integrating technology in their instruction. Results revealed that biology teachers' TPACK is low. This suggests biology teachers still face some difficulties in integrating content knowledge, pedagogy, and technology in teaching classification of living things in the classroom (Putri, et al., 2019).

In summary, previous research highlighted several factors that influence TPACK broadly for pre-service and in-service teachers. This includes, teachers' self-efficacy with using technology in their classrooms (Aquino, 2015), gender differences in instructors' integration of technology in their classrooms (Aquino, 2015), teachers' mastery of TPACK (Paidy et al., 2020), and using CoRes to evaluate TPACK as a guide to influence their technology-integrated instruction (Nasution et al., 2017; Putri et al., 2020). What these studies demonstrate is that TPACK and its integrated constructs are highly influenced by additional variables.

These studies also tend to focus on the sub-components of TPACK such as pedagogical knowledge (PK) and technological knowledge (TK) related to instruction. What they often leave out is the integrated role of technology content knowledge (TCK) to TPACK and how TPACK influences technology integration in the classroom. As such, a few studies have validated the conceptual structure of the TPACK Framework using educational technologies in specific subject areas (Harris et al., 2017). To address this

gap this research focused on educational technology integration in the discipline of biology using the TPACK and Technology Integration Matrix (TIM) Frameworks to understand Technological Pedagogical and Content Knowledge integration in higher education biology instructors (i.e. tenure faculty, graduate teaching assistants (GTA). A detailed description of the Technology Integration Matrix is provided in the following section.

### ***The Technology Integration Matrix***

The Technology Integration Matrix (TIM) was created for K-12 teachers as a resource for administrators to evaluate teacher instruction with educational technologies in the classroom. The TIM evaluation Framework was also developed to be a tool for helping target professional development in the use of educational technologies (Sandholtz et al., 1997). During the development of the TIM Framework, focus groups and interviews were conducted with K-12 teachers and educational technology specialists to validate the matrix and its descriptive components (Florida Center for Instructional Technology, 2005). The TIM Framework is a two-dimensional matrix (Figure 3-2). The first dimension is instructor-designed learning environments (Active, Constructive, Authentic, Collaborative, and Goal-Directed), and the second dimension is five hierarchical levels of technology integration (Entry, Adoption, Adaptation, Infusion, and Transformation). This five-by-five matrix results in a total of twenty-five cells that describe levels of educational technology integration across different potential classroom environments. Each cell in the matrix has descriptions to explain both the learning environment and technology integration characteristics at each level. The TIM Framework can help describe the variation in levels of educational technology integration

in classroom settings (Harmes et al., 2016). An important goal of TIM is to explore instructor technology use in their classrooms by describing the varying levels of technology use in terms of specified learning tasks (Attard & Holmes, 2020). An outcome TIM use would be to design professional development to address challenges in technology integration. For example, a study revealed that there was a positive correlation between technology integration, as measured with the TIM Framework that increased student engagement (U.S. Department of Education, 2017). This positive outcome encouraged more professional development opportunities which in turn supported student-centered technology integration in the K-12 classrooms by the implementation and reflection on teacher observations (Barbour, 2014; Francis, 2017).

Figure 3-2

## The Technology Integration Matrix Table Summary

Levels of Technology Integration →		ENTRY LEVEL	ADOPTION LEVEL	ADAPTATION LEVEL	INFUSION LEVEL	TRANSFORMATION LEVEL
		The teacher begins to use technology tools to deliver curriculum content to students.	The teacher directs students in the conventional and procedural use of technology tools.	The teacher facilitates the students' exploration and independent use of technology tools.	The teacher provides the learning context and the students choose the technology tools.	The teacher encourages the innovative use of technology tools to facilitate higher-order learning activities that may not be possible without the use of technology.
Characteristics of the Learning Environment	ACTIVE LEARNING Students are actively engaged in using technology as a tool rather than passively receiving information from the technology.	<b>Active Entry</b> Information passively received	<b>Active Adoption</b> Conventional, procedural use of tools	<b>Active Adaptation</b> Conventional independent use of tools; some student choice and exploration	<b>Active Infusion</b> Choice of tools and regular, self-directed use	<b>Active Transformation</b> Extensive and unconventional use of tools
	COLLABORATIVE LEARNING Students use technology tools to collaborate with others rather than working individually at all times.	<b>Collaborative Entry</b> Individual student use of tools	<b>Collaborative Adoption</b> Collaborative use of tools in conventional ways	<b>Collaborative Adaptation</b> Collaborative use of tools; some student choice and exploration	<b>Collaborative Infusion</b> Choice of tools and regular use for collaboration	<b>Collaborative Transformation</b> Collaboration with peers, outside experts, and others in ways that may not be possible without technology
	CONSTRUCTIVE LEARNING Students use technology tools to connect new information to their prior knowledge rather than to passively receive information.	<b>Constructive Entry</b> Information delivered to students	<b>Constructive Adoption</b> Guided, conventional use for building knowledge	<b>Constructive Adaptation</b> Independent use for building knowledge; some student choice and exploration	<b>Constructive Infusion</b> Choice and regular use for building knowledge	<b>Constructive Transformation</b> Extensive and unconventional use of technology tools to build knowledge
	AUTHENTIC LEARNING Students use technology tools to link learning activities to the world beyond the instructional setting rather than working on decontextualized assignments.	<b>Authentic Entry</b> Technology use unrelated to the world outside of the instructional setting	<b>Authentic Adoption</b> Guided use in activities with some meaningful context	<b>Authentic Adaptation</b> Independent use in activities connected to students' lives; some student choice and exploration	<b>Authentic Infusion</b> Choice of tools and regular use in meaningful activities	<b>Authentic Transformation</b> Innovative use for higher-order learning activities connected to the world beyond the instructional setting
	GOAL-DIRECTED LEARNING Students use technology tools to set goals, plan activities, monitor progress, and evaluate results rather than simply completing assignments without reflection.	<b>Goal-Directed Entry</b> Directions given; step-by-step task monitoring	<b>Goal-Directed Adoption</b> Conventional and procedural use of tools to plan or monitor	<b>Goal-Directed Adaptation</b> Purposeful use of tools to plan and monitor; some student choice and exploration	<b>Goal-Directed Infusion</b> Flexible and seamless use of tools to plan and monitor	<b>Goal-Directed Transformation</b> Extensive and higher-order use of tools to plan and monitor

Note. Adapted from: Florida Center of Instructional Technology, 2005

Even though there is a widespread interest, the number of studies investigating biology instructors' technology integration through a TPACK and TIM lens is limited. There is widespread of interest in understanding how teaching practices are influenced by an increasingly digitized society (Harris & Yearta, 2019; Walan, 2020) including the relationships between technology integration and the factors that influence biology instructors' integration in the classroom (Juanda et al., 2021; Walan, 2020). This study drew on Mishra & Koehler's (2006) TPACK Framework, which emphasized the connections, interactions, affordances, and or constraints between, and among the three

primary domains (PK, CK, and TK) and the Technology Integration Matrix Framework that evaluates teachers' technology integration (Florida Center of Instructional Technology, 2005). When used in productive ways, both Frameworks can contribute to enhancing technology integration in the classroom.

### **Research Questions**

In light of the above statements, we used the TPACK and TIM Framework to investigate how biology instructors' TPACK and experiences using educational technologies influence their technology integration comfort level.

We specifically sought to learn:

1. How do biology instructors define educational technology?
2. What is the technological pedagogical content knowledge (TPACK) of biology instructors at higher education institutions?
  - 2a. How does TPACK differ by instructor type?
3. What are biology instructors' at higher education institutions perceived technology integration levels?
  - 3a. How does technology integration level differ by instructor type?
4. How does TPACK influence biology instructors' technology integration?

### **Methods**

A cross-sectional survey research design was used to answer the above research questions. Data were collected primarily from the Higher Education-TPACK survey (HE-TPACK) (Garrett, 2014). New multiple-choice items about technology integration levels

were developed from the Technology Integration Matrix for this study and included as part of the survey (Florida Center of Instructional Technology, 2005; Meigs, 2010). The survey as well as its validity and reliability determination is discussed in more detail below.

### **Sampling**

The participants for this study were post-secondary biology instructors (i.e., tenured professors, non-tenure professors, and graduate teaching assistants) at two and four year higher education institutions across the United States. This sample allowed for an exploration of differences amongst biology instructors at two and four-year institutions. (Research questions 2a and 3a). Four-year universities and two-year colleges are defined as follows (The Carnegie Classification of Institutions of Higher Education, 2017):

*Four-year universities:* The majority of undergraduate degrees awarded by these institutions were bachelor's degrees.

*Two-year colleges:* These institutions awarded associate's degrees but no bachelor's degrees with typically more than 75% of awards in a single career & technical program.

To determine the appropriate sample size for the study, the U.S. Bureau of Labor Statistics was consulted. The number of current biology instructors who teach at higher education institutions in the United States is 48,330 (bls.gov, 2020). This research evaluated instructors that teach introductory biology courses (i.e. general biology, and introductory biology) because those courses are necessary for undergraduates to progress through their chosen major (Smith et al., 20112). The gateway introductory biology courses specifically contain content and skill students need to be successful in future

biology courses (Ferrare, 2019; Smith et al., 2012). Therefore, because we were interested in the biology instructors that teach gateway courses we narrowed down the number of instructors (4,150), the general biology instructors (2,670), and general life science instructors (1,480) (bls.gov, 2020). According to Martinez-Mesa et al. (2014), good maximum sample size for survey research to achieve optimal statistical power is around 10% of the target population. Ten percent is a total survey sample of  $n=415$ . This study recruited  $n=117$  participants, and  $n=90$  completed the survey. The process for recruitment of this sample is described in more detail below.

### **Recruitment of Participants**

An intentional sampling method was used with additional snowball sampling. We recruited participants through the National Association for Research in Science Teaching (NARST), the Society for the Advancement of Biology Education Research (SABER), Biology Teaching Assistant Project (BioTAP) listservs, and personal networks. The various organizations and institutions allowed us to recruit participants from diverse educational backgrounds with a variety of different perspectives and experiences. All taught gateway introductory biology courses and had to adhere to the following inclusion criteria.

### **Participant inclusion criteria**

To be included in this study, participants had to:

1. Be actively teaching an introductory undergraduate biology course (i.e., Introductory Biology, General Biology, Anatomy & Physiology) at either a two-year or four-year higher education institution, and must be employed by the biology department.

2. Have at least one semester of teaching experience with educational technology (e.g. computer simulations, video animations, software)

### **Survey Description**

To collect the data, we distributed an electronic version of the survey that asked participants about how they define educational technology in an open-ended question, their perceived TPACK (utilizing the HE-TPACK survey), and their perceptions of technology integration in their classrooms (using the newly developed TIM items). Qualtrics software (Qualtrics, 2021) was used to collect participant responses. A detailed description of the content, reliability, and validity of the survey is discussed below.

### **HE-TPACK Survey**

The HE-TPACK survey is an instrument that measures higher education faculty TPACK and was adapted and used for this study (Garrett, 2014). Garrett (2014) designed the instrument for higher education faculty to assess their perceptions of their knowledge of TPACK (See Figure 3-1). The items that assessed the seven TPACK domains include pedagogical knowledge (PK), technology knowledge (TK), content knowledge (CK), pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), and technological pedagogical content knowledge (TPACK). The HE-TPACK survey has 45 items and was originally modified by Garrett from the pre-service teacher (PT-TPACK) survey created by Lux et al. (2011). The HE-TPACK survey was based on five-point Likert scale items that rate responses for each of the seven TPACK Framework domains. The Likert scale consisted of: 1= *Strongly Agree*, 2 = *Agree*, 3 = *Not Sure*, 4 = *disagree*, and 5 = *Strongly disagree*. The number of items from the HE-TPACK survey per domain is shown in Table 3-1 below.

**Table 3-1***HE-TPACK Survey Per Domain*

<i>Number of survey items per TPACK Domain</i>	
<i>Domains</i>	<i>Number of Survey Items</i>
PK	4
TK	6
CK	6
PCK	6
TPK	6
TCK	6
TPACK	11
Total	45

*HE-TPACK Survey Validity and Reliability*

Garrett (2014) collected content validity evidence with five expert reviewers trained in TPACK and/or technology. During the review process, the survey items were evaluated for wording, grammar, and ambiguity (Crocker & Algina, 1986). The five expert reviewers wanted to ensure each item on the survey sufficiently measured the TPACK domains. The content validity evaluation included feedback on the design and development of the survey items. Comments from those reviews were incorporated into the final version of the survey instrument. The review process generated content validity evidence of the HE-TPACK survey to ensure that it served as a useful measurement of higher education faculty TPACK (Crocker & Algina, 1986).

To measure the degree of item consistency within each of the domains in the HE-TPACK survey (Garrett, 2014), reliability was established through Cronbach's alpha calculations (See Table 3-2). The Cronbach's alpha values calculated were from the

original administration of the HE-TPACK Survey (Garrett, 2014). There were 128 participants (n=128) from the Garrett (2014) study, which consisted of the tenured track, non-tenured track and graduate teaching assistants. All survey items were kept for each domain in the original study (Garrett, 2014).

**Table 3-2**

*Cronbach's Alpha Summary*

<b>Domain</b>	<b>Cronbach's Alpha</b>	<b>Number of Items</b>
Pedagogical Knowledge (PK)	.863	4
Technology Knowledge (TK)	.739	6
Content Knowledge (CK)	.822	6
Pedagogical Content Knowledge (PCK)	.822	6
Technological Pedagogical Knowledge (TPK)	.805	6
Technological Content Knowledge (TCK)	.776	6
Technological Pedagogical Content Knowledge (TPACK)	.922	11

### **Survey Modification Process**

For this study, the HE-TPACK survey instrument was modified to accommodate higher education biology instructors in addition to the technology integration-related items. This modification included changing generic wording in the original survey to

discipline-specific terminology related to biology. For example, one original survey item states, “I understand how to integrate technology to build upon students’ knowledge of curriculum content” (Garrett, 2014). The modified statement now reads, “I understand how to integrate educational technology to build upon students’ biology concepts knowledge (e.g., transcription and translation)”. The Likert Scale was slightly modified also to have the “agreeable” items assigned to higher values and the “disagreeable” items assigned to lower values to allow for easier interpretation of the outcomes during analysis.

To assess perceptions of biology instructors’ technology integration level, two items were developed by the researchers and added to the HE-TPACK survey adapted from the Florida Center of Instructional Technology (2005) Technology Integration Matrix (TIM). The TIM items were added to the survey to determine if TPACK perception was influenced by technology integration in the classroom, as well as whether the perceptions predicted the level of technology integration (Research Questions 2 and 3). The items were generated from the descriptors from the Technology Integration Matrix. The first item assessed the biology instructors’ perceived classroom learning environment while using educational technology to teach. Based on the response participants selected for the classroom-learning environment item, the survey then directed them to the appropriate response choices corresponding with the matrix descriptors for levels of technology integration. For example, if they chose the active learning environment they were directed to the five active learning teaching descriptors as described below. The environment example and the technology integration example below each response align with the TIM Framework.

***Environment example question are below:***

54. Which of the following best describe your classroom environment when integrating an educational technology?
- a. Students are engaged in using technology as a tool rather than passively receiving information from the technology.
  - b. Students use technology tools to collaborate with others rather than working individually at all times.
  - c. Students use technology tools to connect new information to their prior knowledge rather than to passively receive information.
  - d. Students use technology tools to link learning activities to the world beyond the instructional setting rather than working on decontextualized assignments.
  - e. Students use technology tools to set goals, plan activities, monitor progress, and evaluate results rather than simply completing assignments without reflection.

***Technology Integration Level example question are below:***

55. In your classroom which scenario is most likely to be accurate?
- a. The teacher may be the only one actively using technology. This may include using presentation software to support delivery of a lecture. The teacher may also have the students' complete drill and practice activities on computers to practice basic skills, such as typing.
  - b. The teacher controls the type of technology and how it is used. The teacher may be pacing the students through a project, making sure that they each complete every step in the same sequence with the same tool. Although the students are more active than students at the Entry level in their use of technology, the teacher still strongly regulates activities.
  - c. The teacher allows for some student choice and exploration of technology tools. Because the students are developing a conceptual and procedural knowledge of the technology tools, the teacher does not need to guide students step-by-step through activities. Instead, the teacher acts as a facilitator toward learning, allowing for greater student engagement with technology tools.
  - d. The teacher guides, informs, and contextualizes student choices of technology tools and is flexible and open to student ideas. Lessons are structured so that student use of technology is self-directed.
  - e. The teacher serves as a guide, mentor, and model in the use of technology. The teacher encourages and supports the active engagement of students with technology resources. The teacher facilitates lessons in which students are engaged in higher-order learning activities that may not have been possible without the use of technology tools. The teacher helps students locate appropriate resources to support student choices

If for Question 54: Which of the following best describes your classroom environment when integrating an educational technology? they select “A. Active: Students are engaged in using technology as a tool rather than passively receiving information from the technology” then in Question 55 they were directed to the active teaching options and select “C. The teacher allows for some student choice and exploration of technology tools. Because the students are developing a conceptual and procedural knowledge of the technology tools, the teacher does not need to guide students step-by-step through activities. Instead, the teacher acts as a facilitator toward learning, allowing for greater student engagement with technology tools.” Then that participant was in the two-dimensional rubric cell of “Active Adaptation” which is the conventional independent use of educational technology and students have a choice and exploration (Florida Center of Instructional Technology, 2005). The descriptors from the example are highlighted in the Figure (see Figure 3-2 above).

The last item added to the HE-TPACK survey was an open-ended question. The open-ended prompt asked biology instructors to give their definition of educational technology. The question was: How would you define educational technology? This question was added to the survey to understand how instructors conceptualize the technology they use in the classroom.

#### *Modified Survey Expert Review*

The modified survey went through a review with four doctoral students in biology education, two biology tenured faculty, one doctoral student in biology, and one post-doctoral scholar in biology education to establish evidence for content validity. During the expert review process, the participants read the proposed research questions, reviewed

the modified survey, and tracked feedback in Google Docs. Next, the expert reviewers attended a focus group Zoom session to discuss their feedback and come to a consensus. The reviewers discussed their overall thoughts about the survey and any suggested changes. Based on the expert feedback, the survey was revised for content and grammar. Redundant questions from the original survey were removed. After the survey was revised it was piloted with biology instructors (i.e., faculty, adjunct, GTA) at various colleges. Validity evidence from the expert review helped support the item content and construct validity (See modified survey in Appendix B).

### **Data Analysis**

Inductive coding was used to help answer research question one, How do biology instructors define educational technology? Dedoose was used to code textual units (i.e. sentences, words) from participant's open-ended responses (Salmona et al., 2020). Pre-existing codes were not used for the open-ended response because we did not want to force-fit responses to better understand the participant's perception of educational technology (Miles et al., 2020). Emergent codes were recorded in Dedoose including descriptions, and a brief data example to develop the codebook (Elliott, 2018). This codebook (Table 3-5) was used to ensure inter-rater reliability during coding in Dedoose by two independent researchers.

Descriptive statistics were calculated for the entire sample (n=90). Specifically, taking the central tendency (i.e., mean, median, mode) and variability measures (i.e., standard deviation, standard error) for all items defining the TPACK domains. Descriptive statistics helped determine the frequency of biology instructors' overall TPACK scores and each domain score. The technology integration level categories were

given numerical values to analyze and categorize statistically (Cox, 1980; Garland, 1991). A 5-point Likert scale was assigned to the different technology integration environments for example; “active learning” was given a value of 1 and “goal-directed” was given a value of a 5. Levels of technology integration were also given values “entry-level” was given a value of 1 and “transformation level” was a 5. The environment and integration level combined determined participants’ technology integration level scores. For example, if a participant chose the prompt for “active learning” =1 and “entry-level”=1 their overall TIM cell code would be 2. This assessed an overall view of biology instructors’ TPACK and technology integration across the entire sample. See Appendix C for an overall assessment of technology integration evaluation scores & criteria. This analysis helps answer RQ2: What is the technological pedagogical content knowledge (TPACK) of biology instructors at higher education institutions? and RQ3: What are biology instructors at higher education institutions’ perceived technology integration levels?

To answer RQ2a: How does TPACK differ by instructor type? and RQ3a: How do technology integration levels differ by instructor type? a violin plot was used to observe the distribution of data. An independent sample ANOVA was used to determine statistical differences between TPACK domains and instructor type as well as technology integration scores and instructor type.

Since we are interested in how TPACK influences biology instructors’ technology integration a scatterplot and correlation analyses were used to investigate the relationship between TPACK domain scores and Technology Integration level scores. Lastly, a

Hierarchical Cluster Analysis in line with Quinnell et al. (2018) was conducted to further answer RQ4: How does TPACK influence biology instructors' technology integration? The purpose of this analysis cluster individuals within the sample by TPACK domain scores and compare technology integration levels across clusters. This analysis groups survey responses to TPACK domain scores across participants together according to similar response patterns. This assisted in understanding emergent patterns in TPACK and TIM outcomes (Quinnell, et al., 2018). Clusters were established using the mean scores for TPACK domains from the survey data (Ward's method) (Prosser et al., 2000; Trigwell et al., 1999; Quinnell et al., 2012). There were no previous cluster analyses performed with similar participants, therefore there was no *a priori* predicted number of clusters. The TPACK scores were used as the grouping variable to generate the emergent clusters to understand the overall relationship between TPACK scores and technology integration and other demographics (i.e., years of teaching experience).

## **Results**

The sample consisted of 90 biology instructors. Demographics based on gender, ethnicity, academic status, and years of experience were collected from each study participant. The sample was 68% female (n =60) and 28% male (n =25) and 4% unidentified (n=5). The sample indicated that 40% were tenured faculty (n =36); 23% were graduate teaching assistants (GTA) (n =21); 21% were non-tenured faculty (n = 19); 9% were other (i.e. retired but teaching full-time) (n =8), 4% were post-docs (n =4), and 3% were adjunct instructors (n=2). Full sample demographics can be found below in

Table 3-3.

**Table 3-3***Participant Demographics*

	<b>Response</b>	<b>Sample Size</b>	<b>Percentage</b>
<b>Gender</b>	Female	60	68%
	Male	25	28%
	Self-Identified	5	4%
<b>Instructor Type</b>	Tenured	36	40%
	GTA	21	23%
	Non-Tenured	19	21%
	Postdoc	4	4%
	Adjunct	2	3%
	Instructor		
	Other	8	9%
<b>Years of Teaching Experience</b>	1-3	18	20%
	4-7	23	26%
	5-11	17	19%
	12-15	8	9%
	16+	24	26%
<b>Course Taught Spring 2021</b>	General Biology (majors)	54	60%
	Introductory Biology (non-majors)	23	26%
	Human Anatomy & Physiology	10	11%
	Other	3	3%
<b>Type of Online Classroom</b>	asynchronous	23	26%
	synchronous	42	46%
	hybrid	25	28%

*Note.* n= 90. Reflects the number and percentage of participants answering “yes” to demographic questions.

### **Confirmatory Factor Analysis**

To provide validity evidence to the modified survey instrument a confirmatory factor analysis (CFA) was conducted to test the suitability of the instrument. According to Hair et al. (2014) CFA analysis is used to validate the extent to which the instrument measures variables that represent items shown constructs. For this study, a CFA was chosen to test if the data fit the theoretically expected TPACK domains (Schmitt, 2011) by testing the items and internal consistency of the full TPACK scale. Overall, the item loadings to the pre-hypothesized factors were statistically “as expected.” Table 3-4 is an index of factor loadings per item from the modified survey instrument. There were some items with somewhat low beta values with values  $\leq 0.5$  (TCK1=0.466; CK3=0.488) indicating item discrimination (Schmidt et al., 2020). Future researchers may want to take note of these items and possibly reword them or remove them from the instrument.

**Table 3-4**

*CFA Factor Loadings*

Latent Factor	Indicator	Factor Loadings				
		B	SE	Z	p-value	$\beta$
Pedagogical Knowledge (PK)	PK1	0.767	0.073	10.541	0	0.767
	PK2	0.756	0.055	13.671	0	0.756
	PK3	0.813	0.056	14.383	0	0.813

	PK4	0.569	0.08	7.151	0	0.569
	TK1	0.797	0.054	14.861	0	0.797
Technology Knowledge (TK)	TK2	0.557	0.067	8.343	0	0.557
	TK3	0.574	0.085	6.72	0	0.574
	TK4	0.789	0.048	16.398	0	0.789
	CK1	0.728	0.074	9.896	0	0.728
Content Knowledge (CK)	CK2	0.596	0.089	6.715	0	0.596
	CK3	0.488	0.1	4.899	0	<b>0.488</b>
	CK4	0.627	0.073	8.56	0	0.627
	PCK1	0.671	0.094	7.174	0	0.671
Pedagogical Content Knowledge (PCK)	PCK2	0.811	0.057	14.216	0	0.811
	PCK3	0.762	0.058	13.201	0	0.762
	PCK4	0.618	0.089	6.942	0	0.618
	TCK1	0.466	0.09	5.182	0	<b>0.466</b>
Technology Content Knowledge (TCK)	TCK2	0.838	0.043	19.699	0	0.838
	TCK3	0.73	0.069	10.619	0	0.73
	TPK1	0.622	0.065	9.593	0	0.622
Technology Pedagogical Knowledge (TPK)	TPK2	0.848	0.034	25.032	0	0.848
	TPK3	0.71	0.06	11.781	0	0.71
	TPK4	0.831	0.036	22.762	0	0.831
Technological Pedagogical & Content Knowledge	TPACK1	0.763	0.063	12.139	0	0.763
	TPACK2	0.82	0.054	15.152	0	0.82

(TPACK)	TPACK3	0.71	0.059	12.041	0	0.71
	TPACK4	0.79	0.045	17.499	0	0.79

---

*Note.* Bolded  $\beta$  values are low.

### **How do biology instructors define educational technology?**

To better understand participants' perception of educational technology an open-ended question was examined, how do biology instructors define educational technology? After an initial analysis of the open-ended responses, seven common themes emerged from biology instructors' descriptions of educational technology. The emerging themes included student learning, software, and hardware, assistance with teaching, tools, electronic devices, student engagement, and resources. All Biology instructors described educational technologies using one of the three categories, most often (1) Software & Hardware (2) Student Learning, and (3) Assist teaching, there is also overlap between codes. The three categories were used to group educational technology definitions of biology instructors. A detailed inductive codebook can be found in Table 3-5. Each of the inductive codes are represented in Figure 3-3 with frequency counts of the percentage of how often instructors mentioned a code category in a given quote. A co-occurrence table is displayed in Table 3-6 to visualize how often a combination of two codes was linked to an instructor response.

Prior research defined educational technology as classroom technology to support student learning (Guzey & Roehrig, 2012; Kopcha, 2010; National Research Council, 2012; Oliveira et al., 2019). Similarly, participants' from this study defined educational technology as a technology that enhances student learning and added the types of educational technology they were familiar with (i.e. software). When defining

educational technology biology instructors mentioned student learning often (i.e. Assess students' skills) (n=64), however, in contrast, student engagement (i.e. student collaboration) was mentioned the least (n= 18). Biology instructors included software & hardware (i.e., digitized resources) in their definitions the most (n=88). Participants who conceptualized educational technology with student learning also identified software and hardware being used. Participants discussed what students were doing while engaging with educational technology in their definition. For example, participant A stated, "Educational technology is software or online platforms that enhance student learning." Similarly, participant B stated, "tools and software that allows students to learn or apply course material, often using computers or online applications." Most instructors agreed that educational technology is designed for student learning and the types of educational technology are either software applications or hardware.

On the other hand, other participants' included all three components student learning, software, and hardware, and assist teaching, and added a 4<sup>th</sup> component, an electronic device. Participant C stated, "Educational technology can be described as digital (i.e., a Learning Management System) or mechanical (i.e., SmartBoards) tools used to help teach/display/illustrate course content, structure student learning opportunities, aid in student assessment, aid in giving formative feedback, or provide a framework for learning analytics."

Instructional technologies deals with the process of using technology for instruction and educational technologies are specific to the development of teaching and learning (Bergdahl et al., 2020; Januszewski & Molenda, 2013). Biology instructors' open-ended responses revealed that they conceptualize educational technology as an

online software or hardware tool that enhances student learning and assists in teaching practices. Participants gave many examples of online instructional technologies. One example given frequently by participants was learning management systems, which are not necessarily categorized as educational technology by researchers if students are not engaging with the technology (Bergdahl et al., 2020). Although instructional technology and educational technology appear to be synonymous, instructional technology is the tool while educational technology is the procedure for using that tool.

**Table 3-5**

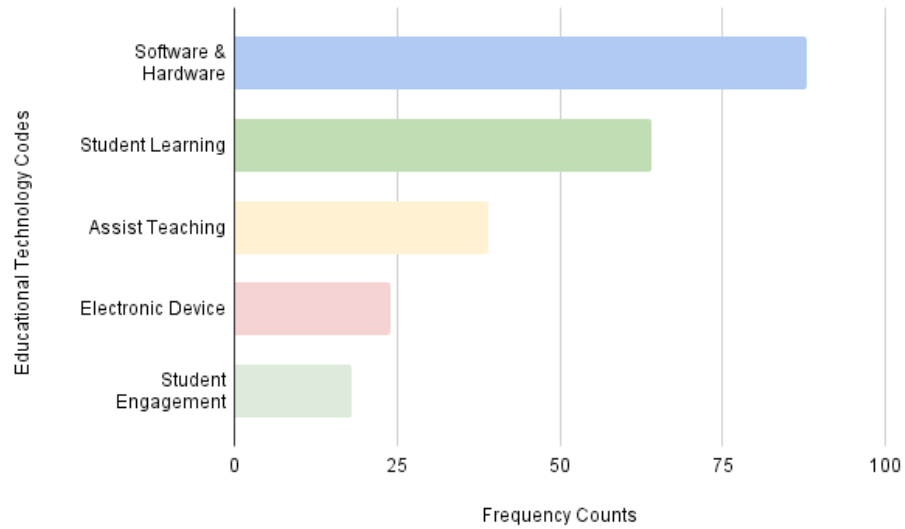
*Education Technology Inductive Codebook*

Inductive Codes	Coding Definitions	Example Quotes
Assist with Teaching	Support teaching, enhance quality of teaching	“Technology used for the purpose of teaching.”
Electronic Devices	Computers, laptops, cell phones, tablet,	“Various computer/phone-based.”
Software & Hardware	Digitized resources, online programs, websites, digital and computational tools	“Apps and programs that can be used to enhance/alter format of teaching and learning. This can be things like polling software, simulations, videos etc.”
Student Engagement	Student collaboration, student-center activities	“Any technological tool that is used inside or outside of the classroom by faculty or students to engage students with course material and increase their understanding of course content.”
Student Learning	Assess students skills, promote student learning	“Educational technology is any technology that can be used to enhance learning

		and allow students to continue learning concepts and possibly allow them to continue learning a skill.”
--	--	---

**Figure 3-3**

*Educational Technology Frequency Counts per Code*



**Table 3-6***Code Co-Occurrence Educational Technology*

	Assist Teaching	Electronic Devices	Software & Hardware	Student Engagement	Student Learning	Total
Assist Teaching						39
Electronic Devices	6					27
Software & Hardware	16	12				88
Student Engagement	2	3	8			18
Student Learning	15	8	23	5		64

*Note.* n=90. This table represents participant responses to the open-ended question prompt from the survey, “how do you define educational technology?” This table shows co-occurrence of particular codes within a single individual respondent.

Overall, results indicate that biology instructors believe educational technologies are software and hardware that enhance student learning and are also beneficial in facilitating instruction. Next, knowing how instructors defined educational technology we wanted to investigate the TPACK of instructors.

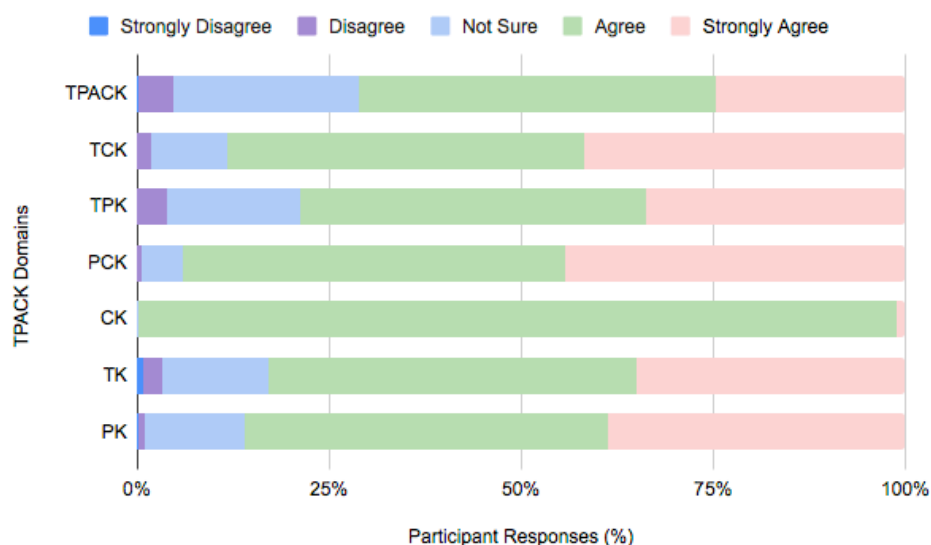
**What is the technological pedagogical content knowledge (TPACK) of biology instructors at higher education institutions?**

The TPACK survey results (Figure 3-4) showed on average, 84% of participants agreed they have a high TPACK score when all item responses were averaged together. However, some domains when separated on average had lower ‘strongly agree’ responses

and higher 'not sure' responses that were obscured in an overall mean score. On average, 25% of participants strongly agreed that they have high TPACK when looked at as a single construct, and 24 % of respondents responded not sure. In the TCK domain on average 42% of participants strongly agreed they have high TCK and 10% of participants were not sure. On average for the TPK domain 34% of participants responded strongly agree and 17% of participants responded not sure. In the TK domain on average 35 % of participants strongly agreed and 14% of participants were not sure. In the PCK domain on average 43% of participants strongly agreed and 5% of participants were not sure. On average 39% of participants strongly agreed with the PK domain and 13% of participants were not sure. In the CK domain on average 53% of participants strongly agreed and 2% of participants were not sure. This indicates that the majority of the participants agreed that they understand the importance of educational technology with content and pedagogical topics, However, participants were not about technological and pedagogical knowledge topics which indicate they may not be as comfortable integrating educational technology into the classroom.

**Figure 3-4**

*Percentage of Participants that Fell Within each Likert Score Range Based on Total Calculated TPACK Mean Score Per Domain*



*Note.* n=90. Total Calculated TPACK Domain Scores is equal to the average Likert score across all items in the TPACK instrument.

Biology instructors' average Likert scores on the CK (Content Knowledge) were highest [M= 4.4; SD= 0.66] and lowest was TPACK domain (Technological Pedagogical Content Knowledge) [M=3.8 SD=0.79]. This indicates that Biology instructors perceive themselves to be knowledgeable of the disciplinary content they teach, but not as knowledgeable in merging the use of technology with content and their existing pedagogy. (See Table 3-7).

**Table 3-7***TPACK Descriptive Statistics*

<b>Domain</b>	<b>Minimum</b>	<b>Maximum</b>	<b>Mean</b>	<b>Std Deviation</b>	<b>Variance</b>
<b>PK</b>	2	5	4.23	0.67	0.46
<b>CK</b>	2	5	4.44	0.66	0.45
<b>TK</b>	1	5	4.13	0.76	0.59
<b>PCK</b>	3	5	4.32	0.62	0.39
<b>TCK</b>	2	5	4.28	0.69	0.49
<b>TPK</b>	2	5	4.08	0.8	0.63
<b>TPACK</b>	2	5	3.88	0.79	0.63

Note. Each domain represents the entire construct. Pedagogical Knowledge (PK)=4 items, Content Knowledge (CK)=4 items, Technology Knowledge (TK)=4 items, Pedagogical Content Knowledge (PCK)=4 items, Technological Content Knowledge=3 items, Technological Pedagogical Knowledge=4 items, Technological Pedagogical Content Knowledge =4 items. All numbers represent a Likert scale.

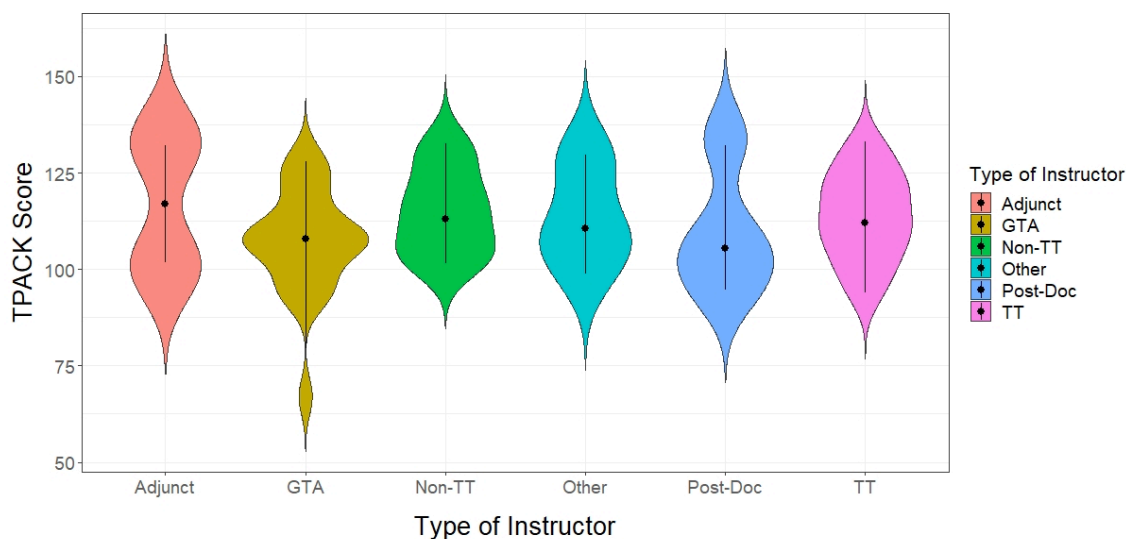
**How does TPACK differ by instructor type?**

Our next question was whether instructor type might influence TPACK. To answer this question TPACK domain scores were summed to create an overall score and plotted by instructor type (Figure 3-5) to show the distribution of the sample. GTAs had both a wider score range as well as lower scores than the other instructor types (*Mdn*=110). Non-tenure track (*Mdn*=120) and Adjuncts (*Mdn*=123) had higher scores than the other instructor types. The shape of the distribution (pink plot) indicates the weights of tenure-track instructors are highly concentrated around the mean. This is an indication Tenure-Track faculty responded more consistently to the TPACK domain items. Additionally, GTAs had extreme outliers in their participant group indicating differences in TPACK scores (brown plot). An ANOVA was used to statistically compare instructors' TPACK across instructor types. There were no statistically significant

differences between overall TPACK and instructor type (See Table 3-8) Therefore, despite qualitative differences in distributions there were no statistical differences found between the groups.

**Figure 3-5**

*Overall TPACK Score Distribution by Instructor Type*



*Note.* Violin plot representing participants TPACK scores by instructor type. TPACK score is a cumulative score across the survey items. GTA= Graduate teaching assistant, Non-TT=Non-Tenure Track, TT=Tenure-Track, Other=Tenured Faculty, Full-time Lecturer.

**Table 3-8**

*ANOVA TPACK by instructor type*

Df	Sum Sq	Mean Sq	F value	Pr(>F)
5	853.8	170.77	1.0787	0.3781

### **What is biology instructors' technology integration level?**

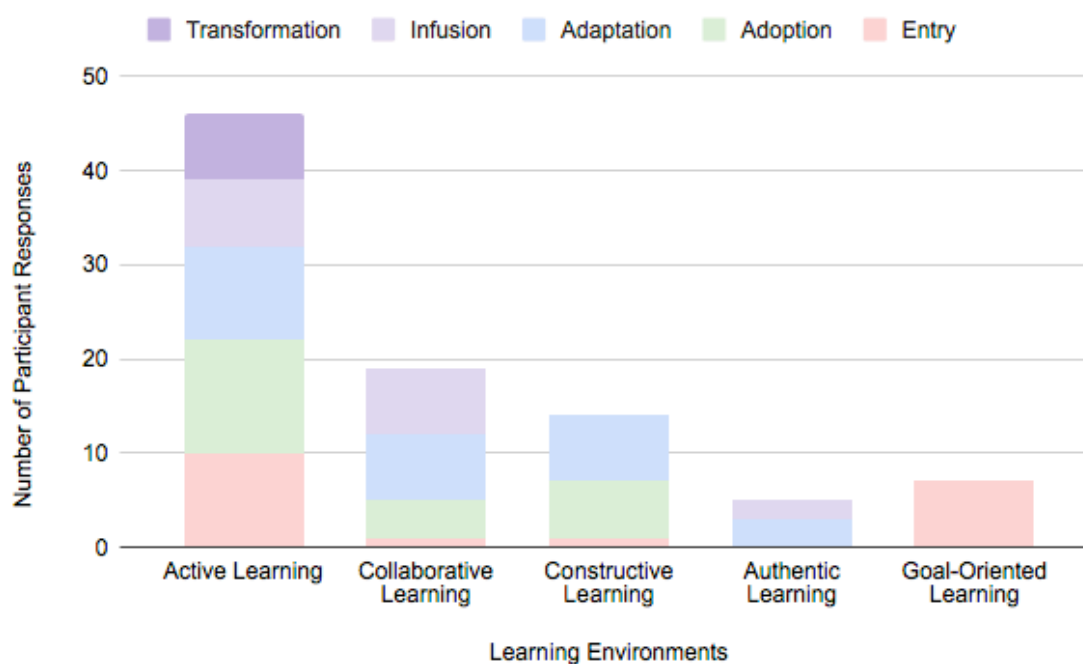
While all measurements up to this point were self-reported efficacy scores, we

next wanted to investigate instructor integration of technology, using the 5x5 Technology Integration Matrix (Figure 3-2). Self-reported descriptors were transformed into quantitative scores by summarizing the environment level (1-5) and integration level (1-25). The lowest possible TIM sum score was a 2 (active environment + entry-level =2), the highest possible TIM sum score was 30 (goal-directed + transformation level = 29). The calculations and evaluation scores are presented in Appendix C.

Participants overwhelmingly believed they had an active learning teaching environment, but a moderate level of technology integration ( $M=15$ ). Participants who self-reported using “collaborative learning” and “authentic learning” environments had higher levels of technology integration, primarily at the infusion level. A Chi-square test was conducted to determine if there were differences in the average scores of the biology instructors’ perceived technology integration and its environment dimensions;  $X^2 = 36.719$ ,  $df = 16$ ,  $p\text{-value} = 0.002$ . The x-square test rejected the null hypothesis indicating that there are statistically significant differences in the distribution of levels of technology integration across all the different learning environments.

**Figure 3-6**

*Distribution of Technology Integration Level Within Participants Categorized by Learning Environment*



*Note.* Each color represents a technology integration level.

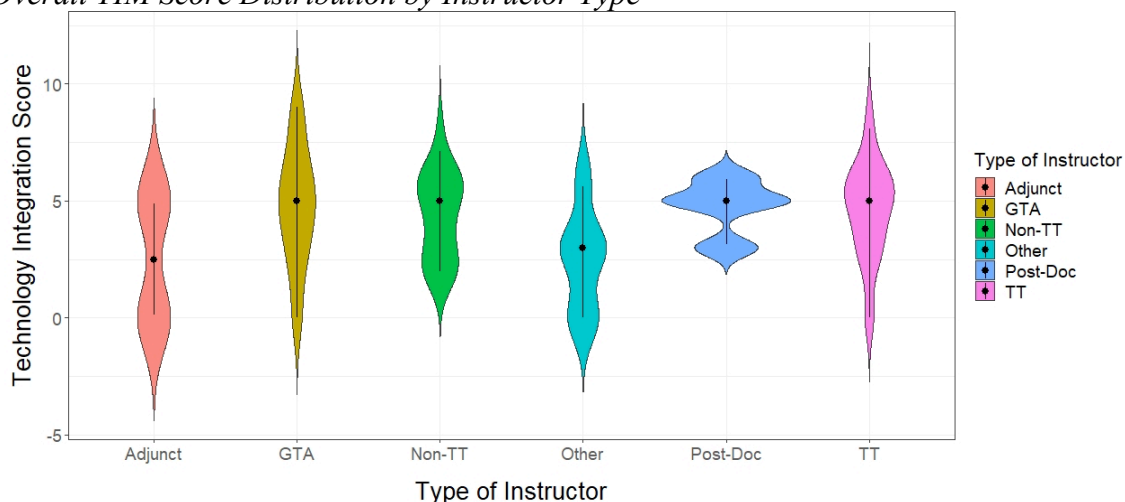
### **How do technology integration levels differ by instructor type?**

Our next research question was whether instructor type might influence the technology integration level. To answer this research question technology integration level scores were summed to create an overall score and plotted by instructor type. An ANOVA was used to compare participants' technology integration levels across instructor types. There were no statistically significant differences between technology integration level and instructor type (See Table 3-9). The distribution and shape of technology integration level by instructor type do appear to qualitatively differ (Figure 3-9). Adjuncts had a lower median score ( $Mdn=3$ ) than the other instructor types. GTAs and non-tenured track instructors had a higher median score ( $Mdn= 5$ ) than the other

instructor types. The largest difference in the distribution of technology integration can be seen in Post-Doctoral Scholars. The overall shape indicates the weights of Post-Doctoral Scholars are not concentrated around the median like the other instructor types and are bimodally distributed. Additionally, GTAs and Tenure-Track instructors' overall shape and distribution are similar, indicating quartiles are very close to one another. These findings indicate that there is some variability in the way biology instructors perceived how they integrate educational technology in the classroom.

**Figure 3-7**

*Overall TIM Score Distribution by Instructor Type*



*Note.* Violin plot representing participant's technology integration scores by instructor type. Technology integration score is a cumulative score across the survey items. GTA= Graduate teaching assistant, Non-TT=Non-Tenure Track, TT=Tenure-Track, Other=Tenured Faculty, Full-time Lecturer.

**Table 3-9***ANOVA Technology Integration Level by Instructor Type*

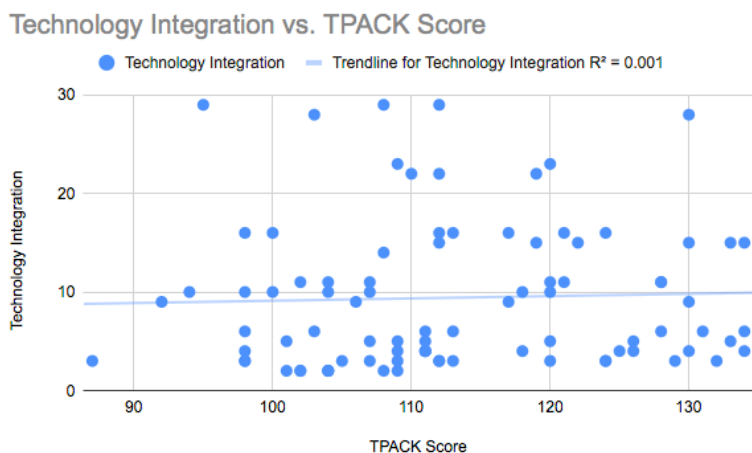
Df	Sum Sq	Mean Sq	F value	Pr(>F)
5	33.73	6.75	1.4235	0.224

**How does TPACK influence biology instructors' technology integration?**

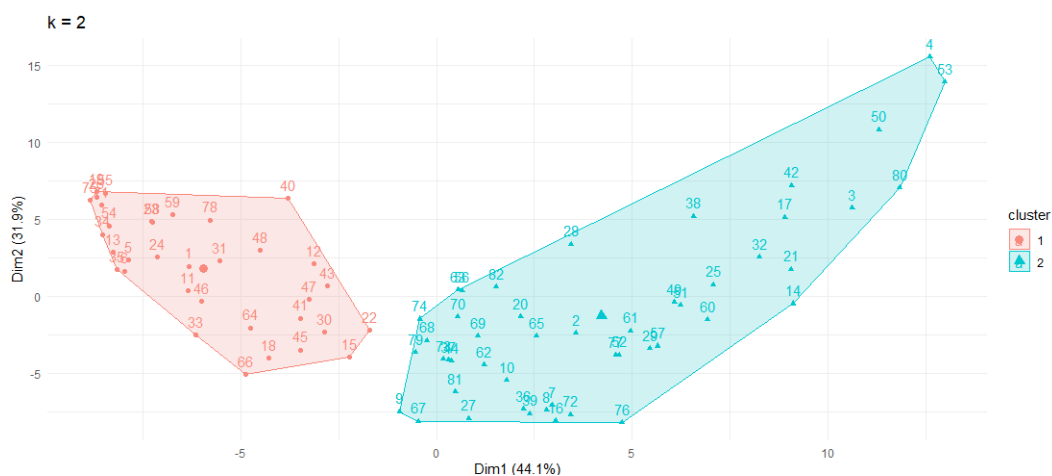
Lastly, our last research question was whether overall TPACK scores influenced biology instructors' technology integration level. To answer this research question a scatter plot was used with a correlational analysis to see if there was a relationship between participant total TPACK scores and technology integration scores. In Figure 3-8 the scatter plot indicated that there was no relationship between TPACK scores and technology integration scores with  $R^2 = 0.001$ . Total TPACK scores were not significantly correlated with technology integration scores (Figure 3-8). To further explore these data, a hierarchical cluster analysis was conducted to group individuals by similarities in TPACK subdomain scores.

**Figure 3-8**

*Relationship Between Overall TPACK and Overall Technology Integration Score*



The hierarchical cluster analysis showed that biology instructors could be grouped into two clusters according to their TPACK domain scores. To investigate the underlying differences between the individuals in each cluster, we first examined TPACK domain scores and found that Cluster 1 individuals agreed with all domains, but cluster 2 individuals agreed primarily with content knowledge domains (CK, PCK, TCK) (Table 3-10).

**Figure 3-9***Hierarchical Cluster Analysis Based on TPACK Domain Scores*

*Note.* Dimension 1 explains 44.1% of variance in the sample. Dimension 2 explains 31.9% of variance within the sample. Numbers represent individual participants.

**Table 3-10***Results from Hierarchical Cluster Analysis Including Sub-Variable for each Cluster*

Cluster	Sub –Variable Means						
	PK	TK	CK	PCK	TCK	TPK	TPACK
1 (N=37)	4.58	4.56	4.74	4.62	4.67	4.54	4.36
2 (N=53)	3.92	3.80	4.18	4.08	4.01	3.70	3.50

*Note.* The numbers represent the mean Likert response for each TPACK construct.

Next, demographic profiles for each cluster were created including instructor type, years of teaching experience, and TIM scores (Table 3-11). A chi-square test of homogeneity was performed to see if there were any statistical differences in the distribution of demographic indicators between each cluster. Demographic indicators included instructor type (i.e. Tenure-Track Faculty, GTA), years of teaching experience

(i.e. 1-3, 4-7 years), and TIM scores (i.e. learning environment, technology integration level). No significant differences were found between Cluster 1 and Cluster 2, with regard to instructor type, ( $\chi^2 = 3.256$ ,  $df = 4$ ,  $p\text{-value} = 0.71$ ), learning environment, ( $\chi^2 = 2.57$ ,  $df = 4$ ,  $p\text{-value} = 0.78$ ), and technology integration levels ( $\chi^2 = 9.31$ ,  $df = 4$ ,  $p\text{-value} = 0.11$ ). However, there are statistically significant differences between Cluster 1 and Cluster 2, with regard to years of teaching experience, ( $\chi^2 = 10.21$ ,  $df = 5$ ,  $p\text{-value} = 0.05$ ). Cluster 1 instructors had more years of teaching experience (12-16+ years) compared to Cluster 2 instructors who had fewer years of teaching experience (1-11 years).

**Table 3-11**

*Results from Hierarchical Cluster Analysis Including Profiles for each Cluster*

	1 (N=37)	2 (N=53)
<b>Instructor Type</b>		
Adjunct Instructor	1 (2.7%)	1 (1.9%)
Faculty Non-Tenure Track	10 (27.0%)	9 (17.0%)
Faculty Tenure-Track	17 (45.9%)	21 (39.6%)
Graduate Teaching Assistant	6 (16.2%)	15 (28.3%)
Other	2 (5.4%)	4 (7.5%)
Post-Doc	1 (2.7%)	3 (5.7%)

**Cont. Table 3-9**

**Years of Experience**

1-3	2 (5.4%)	12 (22.6%)
-----	----------	------------

12-15	5 (13.5%)	3 (5.7%)
16+	13 (35.1%)	11 (20.8%)
4-7	10 (27.0%)	13 (24.5%)
8-11	7 (18.9%)	10 (18.9%)
0	0 (0%)	4 (7.5%)
<b>Learning Environment</b>		
Active Learning	15 (40.5%)	24 (45.3%)
Authentic Learning	2 (5.4%)	3 (5.7%)
Collaborative Learning	8 (21.6%)	11 (20.8%)
Constructive Learning	8 (21.6%)	6 (11.3%)
Goal-Directed Learning	1 (2.7%)	4 (7.5%)
NA	3 (8.1%)	5 (9.4%)
<b>Levels of Technology Integration</b>		
Adaptation Level	11 (29.7%)	15 (28.3%)
Adoption Level	11 (29.7%)	10 (18.9%)
Infusion Level	8 (21.6%)	9 (17.0%)
NA	3 (8.1%)	6 (11.3%)
Transformation Level	4 (10.8%)	3 (5.7%)
Entry Level	0 (0%)	10 (18.9%)

---

*Note.* n= 90. Reflects the number and percentage of participants answering “yes” to demographic questions and choosing technology integration prompt.

## **Discussion**

This work contributes to the Technological Pedagogical and Content Knowledge literature by exploring biology instructors’ TPACK knowledge and technology integration levels and the relationship between the two, as well as other demographic

factors. Understanding the role of TPACK in technology integration is important when thinking about how to increase educational technology integration in biology classrooms. It is aligned with recent studies that suggested understanding technological knowledge and integrating it with content teaching and learning in a specific content area (Celik et al., 2020; Willermark, 2018). To strengthen teaching practice and positive outcomes for students' future studies can explore how educational technologies enhance student interaction to understand how educational technologies affect cognitive and affective engagement. Evaluating how students construct their path of learning by engaging with educational technologies.

First, to reveal patterns associated with instructors' definitions of educational technologies, inductive coding revealed that biology instructors define educational technologies differently. Overall, definitions included enhancing student learning (i.e., assess student skills, promote learning in the classroom), software and hardware (i.e., apps, online programs), and assistance with teaching (i.e., enhancing the quality of teaching). The educational technology examples that participants gave were mostly ways they use technology to facilitate instruction and were not very student interactive. Despite reports the use of educational technology in teaching and learning environments in biology is becoming more common in today's classrooms (Wong & Subramaniam, 2020), we found that how instructors define educational technology varies as much as how they integrate it into the classroom. In line with educational reform efforts, the types of educational technologies that should be considered for classroom implementation are designed to have students actively engaged in the learning process (Castañeda & Selwyn,

2018; Januszewski & Molenda, 2013). According to Castañeda and Selwyn (2018), it is crucial to have a greater understanding of the role that educational technology plays in affecting student engagement.

About differences in instructors' TPACK, findings were that instructors had higher pedagogical content-related scores (i.e., PCK) but lower technological-related scores (i.e., TPK). A direct comparison of TPACK levels from previous studies is difficult, because of varying or modified TPACK surveys (Nantshev et al., 2020), however, earlier research also showed the same trend, with higher pedagogical content-related scores and lower technological-related scores (Fabian et al., 2019; Jaikaran-Doe & Doe, P., 2015; Morales et al., 2019; Scott & Nimon, 2020). Based on these results, instructors are knowledgeable of how to teach their disciplinary content, but not as knowledgeable of integrating technology thinking about content and their existing pedagogy. With these findings researchers can think about why instructors are not as knowledgeable in implementing educational technology and how can technological knowledge be increased. Prior studies have shown that teachers need support and a good understanding of how technology can be integrated with pedagogy and content knowledge to effectively implement it into classroom instruction (Jaipal-Jamani & Figg, 2015; Sheffield et al., 2014) There is a need for promotion of biology instructors' awareness of current educational technologies that can support content-specific pedagogy. One way to help instructors become aware of and comfortable with integrating educational technology in their classrooms is through professional development. Studies have shown that professional development training can improve TPACK levels (Marcelo

& Yot-Dominguez, 2019; Nantschev et al., 2020).

This study evaluated instructors' technology integration as it relates to the learning environment. Findings suggest the most common learning environment was active learning, using the TIM framework. An important goal of the technology integration matrix (TIM) is to understand the level at which instructors use technology in the classroom (Attard & Holmes, 2020). Studies have shown that student engagement is an important factor in technology integration (Castañeda & Selwyn, 2018); our results support this. This indicates that the learning environment matters as to how an instructor integrates educational technology. Our findings suggest graduate teaching assistants had higher technology integration levels than the other instructor types (i.e. tenure track and adjunct instructors). This distinction can explain differences in results.

Research question four, whether overall TPACK scores influenced biology instructors' technology integration level, there was not a direct relationship; however, these results suggest groups of instructors had similar TPACK scores and technology integration levels. Overall, instructors in Cluster 1 (n=37) had higher TPACK scores and technology integration levels than in Cluster 2 (n=53). Another significant distinction between Cluster 1 and 2 was years of teaching experience, Cluster 1 had 12-16+ years compared to Cluster 2 instructors who had 1-11 years. Although these findings are important to consider, this study differed from Nasution et al., (2017) in that they surveyed biology teachers' TPACK using Content Representation (CoRes) as it relates to the technology integration and pedagogy in teaching. While those findings provide an insight into biology teachers' technology integration and pedagogy using educational

technologies, they leave out variables that may influence technology integration. This study examined biology instructors' TPACK and technology integration as it relates to content and looked at demographic variables (i.e. years of teaching experience, instructor type). This difference can explain the differences in our results. Years of teaching experience contributed to increased self-efficacy of instructors' TPACK. The more teaching experience the higher the TPACK scores. This could be due to years of training and experience in integration educational technology. Moving forward researchers can explore the factors that influence biology instructors' educational technology integration in the classroom.

### **Limitations of the Study**

While the findings provide implications for future research on technology integration, there are limitations to the methodology and results that should be taken into consideration. One limitation of this study is the sample (n=90) limits the generalizability of these findings to other higher education institution contexts. Acknowledging the participants in this study all have unique perspectives, generalizing data across participants may not adequately represent this population of instructors. The sample size was used based on the convenience of listserv affiliations at the time of the study. Future research should help support any statistical differences that were found in this study with a different sampling method, for example, random samples to support generalizability.

### **Implications for Future Research**

Before the COVID-19 pandemic, educational technologies were implemented in higher education biology classrooms, but not efficiently or often (Kier & Johnson, 2022).

Now presently in the pandemic, we feel the impact and the need for effective educational technology integration (Kier & Johnson, 2022; Valverde-Berrocoso et al., 2021). One way to help biology instructors effectively integrate educational technology in the classroom is through TPACK and technology integration development. Because this research sought to understand TPACK and its impact on educational technology integration, it provides researchers and instructors insight into TPACK, and ways to integrate technology. Our results did not find any relationships between technology integration levels and TPACK, therefore future research can explore how to help instructors make this connection. Helping instructors develop this connection can ultimately help promote 21<sup>st</sup>-century learners and prepare students for the digitized world in which they live (Smith & Mader, 2016).

Across educational settings, instructional technologies (i.e. Zoom, Online Platforms) are being used more often within the classroom than educational technologies (i.e. virtual simulations, interactive videos). Available resources, and methodologies to measure student learning and instructor integration are limited. There is also limited research on the impacts of educational technology on student learning. Because instructional technologies create a space where educational technologies can be used, it can be challenging to collect and analyze data at the individual-instructor level, due to the variety of instructional technologies and educational technologies available. Future research should develop workshops and reflection opportunities to capture the diversity of instructors' perception of technology integration and its impacts on student learning. Moving this area of research forward can provide a meaningful evaluation of educational

technology integration that helps to improve instruction.

### **Conclusion**

Our work addressed the gap in the literature by exploring biology instructors' TPACK and the ways educational technologies are integrated into biology classrooms. What these findings suggest is that there seems to be a gap between instructors' perception of their knowledge and their ability to integrate their technology knowledge into their instruction. There seems to be a disconnect between perceived practice and actual practice related to the use of educational technologies. Further research needs to focus on the complex relationship between TPACK (teacher knowledge) and instructional practice (what they do in the classroom) and what students are learning in the process. It is imperative that future research explores the complexities of TPACK and enhances the effectiveness of educational technology integration through workshops and in-class observations. Classroom observations can help inform instructors of their teaching practice by providing feedback and allowing them to reflect on their observations.

## References

- Allen, D., Brown, A., Karanasios, S., Norman, A. (2013). How should technology-mediated organizational change be explained? A comparison of the contributions of critical realism and activity theory. *MIS Quarterly*, 37, 835-854.
- Allen, G., Guzman-Alvarez, A., Molinaro, M., & Larsen, D. (2015). Assessing the impact and efficacy of the open-access ChemWiki textbook project. *Educause Learning Initiative Brief*. <https://net.educause.edu/ir/library/pdf/elib1501.pdf>.
- Anwaruddin, S. (2015). ICTs in language and literacy education in Bangladesh: A critical review. *Current Issues in Education*, 18(1), 1–12.
- Attard, C., Holmes, K. (2020). An exploration of teacher and student perceptions of blended learning in four secondary mathematics classrooms. *Math Education Research Journal*. <https://doi.org/10.1007/s13394-020-00359-2>.
- Aquino, A. (2015). Self-efficacy on technological, pedagogical and content knowledge (TPACK) of biological science pre-service teachers. *Asia Pacific Journal of Multidisciplinary Research*, 3(4), 150-157.
- Barbour, D.R. (2014). The Technology Integration Matrix and Student Engagement: A Correlational Study.
- Bergdahl, N., Nouri, J. & Fors, U. (2020). Disengagement, engagement and digital skills in technology-enhanced learning. *Education Information Technology*, 25, 957–983 <https://doi.org/10.1007/s10639-019-09998-w>
- Bhakta, K. & Dutta, N. (2016). Impact of information technology on teaching-learning process. *International Research Journal of Interdisciplinary & Multidisciplinary Studies*, 2(11), 131-138.
- Bilici, S., Guzey, S., Yamak, H. (2016). Assessing pre-service science teachers' technological pedagogical content knowledge (TPACK) through observations and lesson plans. *Research in Science Technological Education*, 34(2), 1-15.
- Bond, M., Buntins, K., Bedenlier, S., Zawacki-Richter, O., Kerres, M. (2020). Mapping research in student engagement and educational technology in higher education: a systematic evidence map. *International Journal of Education Technology in Higher Education*, 17(2).
- Bruce, B., & Hogan, M. (1998). The disappearance of technology: Toward an ecological model of literacy. In: D. Reinking, M. Mvkenka, L. Labbo & K. Keiffer, eds. *Handbook of literacy and technology: Transformations in a post-typographic world*. Hillsdale: Erlbaum, 269-281.
- Castañeda, L., Selwyn, N. (2018). More than tools? Making sense of the ongoing digitizations of higher education. *International Journal of Educational Technology in Higher Education*, 15, 22 <https://doi.org/10.1186/s41239-018-0109-y>.
- Celik, C. Guven, G., Cakir, N. (2020). Integration of mobile augmented reality (MAR) applications into biology laboratory: Anatomic structure of the heart. *Research in Learning Technology*, 28. <https://doi.org/10.25304/rlt.v28.2355>
- Chai, C., Koh, J., & Tsai, C. (2013). A review of technological pedagogical content knowledge. *Educational Technology & Society*, 16 (2), 31–51.
- Chang, R., & Yu, Z. (2017). Application of augmented reality technology to promote interactive learning. Proceedings of the 2017 IEEE International Conference on

- Applied System Innovation: Applied System Innovation for Modern Technology, ICASI 2017.
- Cox, E. (1980). The optimal number of response alternatives for a scale: a review. *Journal of Marketing Research* 17(4): 407–442.
- Crocker, L. & Algina, J. (1986). *Introduction to classical and modern test theory*. Harcourt, New York, 527.
- Fabian, K., Clayes, E., & Kelly, L. (2019). Putting design into practice: An investigation of TPACK scores of lecturers in a networked institution. *Research in Learning Technology*, 27.
- Elliott, V. (2018). Thinking about the coding process in qualitative data analysis. *The Qualitative Report*, 23(11), 2850-2861.
- Flogie, A., Barle Lakota, A., & Abersek, B. (2018). The psychosocial and cognitive influence of ICT on competences of STEM students'. *Journal of Baltic Science Education*, 17, 267-276.
- Florida Center for Instructional Technology. (2005-2020). *The technology integration matrix: Adaptation level*, para. 2, University of South Florida, College of Education. Retrieved from <https://fcit.usf.edu/matrix/project/adaptation-level/>.
- Francis, J. (2017). The effects of technology on student motivation and engagement in classroom-based learning. (Published Dissertation). University of New England, Biddeford, Maine.
- Garland, R. (1991). The mid point on a rating scale: Is it desirable? *Marketing Bulletin* 2(1): 66–70.
- Garrett, K. (2014). A quantitative study of higher education faculty self-assessments of technological, pedagogical and content knowledge (TPACK) and technology training. (Published Dissertation). The University of Alabama, Tuscaloosa, Alabama.
- Guzey, S., & Roehrig, G. (2009). Teaching science with technology: Case studies of science teachers' development of technology, pedagogy, and content knowledge. *Contemporary Issues in Technology and Teacher Education*, 9.
- Hair, J., Black, W., Babin, B., & Anderson, R. (2014). *Multivariate data analysis*. New York: Routledge.
- Harmes, C. J., Welsh, J., L., & Winkelman, R., J. (2016). *A Framework for Defining and Evaluating Technology Integration in the Instruction of Real-World Skills*. In *Handbook of Research on Technology Tools for Real-World Skill Development* 137-162. Hershey, PA, USA: IGI Global.
- Harris, J., Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, 9(1), 60-70.
- Harris, J., Phillips, M., Koehler, M., Rosenberg, J. (2017). TPCK/TPACK research and development: Past, present, and future directions. *Australasian Journal of Educational Technology*, 33(3).
- Harris, L. & Yearta, L. (2019). The UDL and TIM as Frameworks for Understanding First Year Teachers' Technology Integration Proficiency. In K. Graziano (Ed.), *Proceedings of Society for Information Technology & Teacher Education International Conference* (pp. 2591-2595). Las Vegas, NV, United States:

- Association for the Advancement of Computing in Education (AACE). Retrieved February 24, 2022 from <https://www.learntechlib.org/primary/p/208016/>.
- Helle, L., Nivala, M., Kronqvist, P. (2013). More technology, better learning resources, better learning? Lessons from adopting virtual microscopy in undergraduate medical education. *Anatomy Science Education*, 6, 73–80, <http://dx.doi.org/10.1002/ase.1302>.
- Hopkins, R., Regehr, G., Wilson, T.D., 2011. Exploring the changing learning environment of the gross anatomy lab. *Acad. Med.* 86, 883–888, <http://dx.doi.org/10.1097/ACM.0b013e31821de30f>.
- Irdalisa, I., Paidi, H., and Djukri, D. (2020). Implementation of Technology-based guided inquiry to improve TPACK among prospective biology teachers. *International Journal of Instruction*, 13(2), 33-44. <https://doi.org/10.29333/iji.2020.1323a>
- Jaikaran-Doe, S., & Doe, P. (2015). Assessing technological pedagogical content knowledge of engineering academics in an Australian regional university. *Australia Asian Journal of Engineering Education*, 20(2), 157-167. <https://doi.org/10.1080/22054952.2015.1133515>
- Jaipal-Jamani, K. & Figg, C. (2015). A Case study of a TPACK-Based approach to teacher professional development: Teaching science with blogs. *Contemporary Issues in Technology and Teacher Education*, 15(2), 161-200.
- Jang, S., & Chen, K. (2010). From PCK to TPACK: Developing a transformative model for pre-service science teachers. *Journal of Science Education and Technology*, 19(6), 553-564. <https://doi.org/10.1007/s10956-010-9222-y>
- Januszewski, A., & Molenda, M. (2013). *Educational technology: A definition with commentary*. Routledge.
- Jenkinson, J., McGill, G. (2012). Visualizing protein interactions and dynamics: Evolving a visual language for molecular animation. *CBE—Life Sciences Education*, (11), 103–110.
- Johnson, L., & Lester, J. (2016). Face-to-face interaction with pedagogical agents twenty years later. *International Journal of Artificial Intelligence in Education*, 26, 25-36.
- Jones, D. (2019). Setting the standards for machine learning in biology. *Nature Reviews Molecular Cell Biology*, 20(11), 659-660. <https://doi.org/10.1038/s41580-019-0176-5>.
- Jose, M., Bonete, G., Jensen, M., Katona, G. (2018). A practical guide to developing virtual and augmented reality exercises for teaching structural biology. *Biochemistry and Molecular Biology Education*, 47(1), 16–24.
- Juanda, A., Shidiq, A. S., & Nasrudin, D. (2021). Teacher learning management: Investigating biology teachers' TPACK to conduct learning during the Covid-19 outbreak. *Journal Pendidikan IPA Indonesia*, 10(1), 48-59.
- Kara, Y. (2018). Determining the effects of microscope simulation on achievement, ability, reports, and opinions about microscope in general biology laboratory course. *Universal Journal of Educational Research*, 6(9), 1981-1990. <https://doi.org/10.13189/ujer.2018.060917>
- Kier, M., & Johnson L.(2022). Exploring how secondary STEM teachers and undergraduate mentors adapt digital technologies to promote culturally relevant

- education during COVID-19. *Education Sciences*, 12(1):48. <https://doi.org/10.3390/educsci12010048>.
- Kiray, S. (2016). Development of a TPACK self-efficacy scale for preservice science teachers. *International Journal of Research in Education and Science (IJRES)*, 2(2), 527- 541.
- Koehler, M. & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, 9(1), 60-70.
- Kopcha, T., Ottenbreit-Leftwich, A., Jung, J., Baser, D. (2014). Examining the TPACK framework through the convergent and discriminant validity of two measures. *Computers & Education*, 78, 87-96.
- Lazarević, T., Miljanović, T., Zupanec, V., & Zarić, G. (2018). The effects of using blog as a web tool in biology teaching in high schools. *Journal of Baltic Science Education*, 3331-342.
- Levesque, A. (2011). Using clickers to facilitate development of problem-solving skills. *CBE—Life Sciences Education*, 10, 406–417 <https://doi.org/10.1145/3337682.333770>
- Maeng, J., Mulvey, B., Smetana, L., Bell, R. (2013). Pre-service teachers' TPACK: Using technology to support inquiry instruction. *Journal of Science Education and Technology*, 22(6). <https://doi.org/10.1007/s10956-013-9434-z>
- Marcelo, C., & Yot-Domínguez, C. (2019) From chalk to keyboard in higher education classrooms: Changes and coherence when integrating technological knowledge into pedagogical content knowledge. *Journal of Further and Higher Education*, 43(7), 975-988. <https://doi.org/10.1080/0309877X.2018.1429584>.
- Martinez-Mesa, J., Gonzalez-Chica, D., Bastos, J., Bonamigo, R., & Duquia, R. (2014). Sample size: How many participants do I need in my research? *Brazilian Society of Dermatology*, 89(4), 609-615. <https://doi.org/10.1590/abd1806-4841.20143705>
- Meigs, R. (2010). Development and pilot of the technology integration matrix questionnaire. (Published dissertation). Baker University, Bladwin City, Kansas.
- Miles, M., Huberman, A., & Saldana, J. (2020). *Qualitative data analysis: A methods sourcebook* (4<sup>th</sup> ed.). SAGE.
- Mishra, P., & Koehler, M. (2006). Technological pedagogical content knowledge: A framework for integrating technology in teacher knowledge. *Teachers College Record*, 108(6), 1017–1054.
- Morales, M., Anito, J., Avilla, R., Abulon, E., & Palisoc, C. (2019). Proficiency indicators for Philippine STEAM (science, technology, engineering, agri/fisheries, mathematics) educators. *Philippine Journal of Science*, 148(2), 263-275.
- Nantshev, R., Feuerstein, E., González, R., Alonso, I., Hackl, W. Petridis, K., Triantafyllou, E., & Ammenwerth, E. (2020). Teaching approaches and educational technologies in teaching mathematics in higher education. *Education Sciences*, 10(354). <https://doi.org/10.3390/educsci10120354>
- Nasution, W., Sriyati, S., Riandi, R., Safitri, M. (2017). Mastery of content representation (CoRes) related TPACK high school biology teacher. *Journal of Physics Conference Series*, 895(1). <https://doi.org/10.1088/1742-6596/895/1/012135>

- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and cored ideas*. Washington, DC, The National Academies Press.
- Niess, M. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and Teacher Education*, 21, 509-523.
- Nurdiani, N., Rustaman, N., Setiawan, W., & Priyandoko, D. (2019). Reasoning patterns and modes of prospective biology teachers on embryology learning with TPACK framework. *Journal Pendidikan Biology Indonesia*, 5(1), 93-100.
- Oliveira, A., Feyzi Behnagh, R., Burgess, K., Guo, L. (2019). Emerging technologies as pedagogical tools for teaching and learning science: A literature review. *Uses of Emerging Technologies, Special Issue Article*, <https://doi.org/10.1002/hbe2.141>
- Pedrosa-de-Jesus, H., Moreira, A., Lopes, B., & Watts, D. (2014). So much more than just a list: Exploring the nature of critical questioning in undergraduate sciences. *Research in Science and Technological Education*, 32(2).
- Petto, A. (2019). Technology meets pedagogy: Comparing classroom response systems. *Research and Teaching*, 48(4).
- Prosser, M., Martin, E., Trigwell, K., Ramsden, P., Lueckenhausen, G. (2005). Academics' experiences of understanding of their subject matter and the relationships of this to their experiences of teaching and learning. *Instructional Science*, 33(2), 137-157.
- Putri, A., Hidayat, T., and Purwianingsih, W.(2020). Analysis of technological pedagogical content knowledge (TPACK) of biology teachers in classification of living things learning. *Journal of Physics: Conference Series*. 1521, 042033.
- Purwianingsih, W.(2020). Analysis of technological pedagogical content knowledge (TPACK) of biology teachers in classification of living things learning. *Journal of Physics: Conference Series*. 1521, 042033.
- Qualtrics, 2005 (2021). Provo, Utah. Available at: <https://www.qualtrics.com>
- Quinnell, R., May, E., Davila, Y., & Peat, M. (2018). Profiling our students' learning orchestrations to evaluate the biology curriculum. *International Journal of Innovation in Science and Mathematics Education*, 26(3), 21-39.
- Quinnell, R., May, E., & Peat, M. (2012). Conceptions of biology and approaches to learning of first year biology students: Introducing a technique for tracking changes in learner profiles over time. *International Journal of Science Education*, 34(7), 1053-1074.
- Reddy, M., & Mint, P. (2017). Impact of simulation based education on biology students' academic achievement in DNA replication. *Journal of Education and Practice*, 8(15).
- Saavedra, A., & Opfer, V. (2012). Learning 21<sup>st</sup>-century skills 21<sup>st</sup>-century teaching. *Phi Delta Kappan*, 94(2), 8-13.
- Salmona, M., Kaczynski, D., Lieber, E., Richards, L., Weisner, T. (2020). *Qualitative and mixed methods data analysis using Dedoose: a practical approach for research across the social sciences*. Thousand Oaks, California: SAGE Publications, Inc.

- Sandholtz, J., Ringstaff, C., Dwyer, D. (1997). *Teaching with technology: Creating student-centered classrooms*. New York; Teachers College Press.
- Schmid, M., Brianza, E., Petko, D. (2020). Developing a short assessment instrument for Technological Pedagogical Content Knowledge (TPACK) and comparing the factor structure of an integrative and a transformative model, *Computers & Education*, 157.
- Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological pedagogical content knowledge (TPACK): The development and validation of an assessment instrument for pre-service teachers. *Journal of Research on Technology in Education*, 42(2), 123-149.
- Schmitt, T. (2011). Current methodological considerations in exploratory and confirmatory analysis. *Journal of Psychoeducational Assessment*, 29(4), 304-321.
- Scott, K., & Nimon, K. (2020). Construct validity of data from a tpack self-assessment instrument in 2-year public college faculty in the United States, *Journal of Research on Technology in Education*.  
<https://doi.org/10.1080/15391523.2020.1790444>
- Sheffield, R. & McIlvenny, L. (2014). Design and implementation of scientific inquiry using technology in a teacher education program. *International Journal of Innovation in Science and Mathematics Education*, 22(6), 46-60.
- Shelly, G., Gunter, G., & Gunter, R. (2012). Teachers discovering computers: Integrating technology in a connected world. *Cengage Learning*.
- Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(1), 4-14.
- Smith, B., & Mader, J. (2016). Science 2.0: When students become digital citizens. *Science Teacher*, 83(8), 8.
- Somyürek, S. (2014). An effective educational tool: Construction kits for fun and meaningful learning. *International Journal of Technology and Design Education*, 25(1), 25-41.
- Srisawasdi, N., Pondee, P., Bunterm, T. (2018). Preparing pre-service teachers to integrate mobile technology into science laboratory learning: an evaluation of technology-integrated pedagogy module. *International Journal of Mobile Learning and Organization*, 12(1), 1-17.
- The Carnegie Classification of Institutions of Higher Education (n.d.). *About Carnegie Classification*. Available at: <https://carnegieclassifications.iu.edu/>.
- Trigwell, K., Prosser, M., Waterhouse, F. (1999). Relations between teachers' approaches to teaching and students' approaches to learning. *Higher Education*, 37, 57-70.
- U.S. Bureau of Labor Statistics. (2020, June 6). Biology instructor's employment summary.
- U.S. Department of Education. (2017). Use of technology in the teaching and learning.
- Valverde-Berrocoso J, Fernandez- Sanchez M., Revuelta Dominguez F., Sosa-Díaz, M. (2021). The educational integration of digital technologies preCovid-19: Lessons for teacher education. *PLoS ONE*, 16(8): e0256283. <https://doi.org/10.1371/journal.pone.0256283>

- Walan, S. (2020). Embracing digital technology in science classrooms: Secondary school teacher's enacted teaching and reflections on practice. *Journal of Science Education and Technology*, 29, 431-441. <https://doi.org/10.1007/s10956-020-09828-6>
- Willermark, S. (2018). Technological Pedagogical and Content Knowledge: A Review of Empirical Studies Published From 2011 to 2016. *Journal of Educational Computing Research*, 56(3).
- Wong, C., & Subramaniam, R. (2020). Use of technology in biology education case of infrared thermal imaging. *Journal of Biological Education*, <https://doi.org/10.1080/00219266.2020/1808510>
- Wu, J. (2016). Learning through Video Production - an Instructional Strategy for Promoting Active Learning in a Biological Course. In S. Barker, S. Dawson, A. Wu, J., Van Nguyen, H., Chen, R., Fan, P. and Loh, K. (2017). *The combined effects of physical and virtual models in learning cellular biology*. In H. Partridge, K.

## CHAPTER IV: STUDY 2

### **Biology Instructors' New Approaches to Teaching After the Covid-19 Pandemic**

*This manuscript will be submitted to CBE-Life Sciences Education*

#### **Abstract**

Online courses have shown steady growth in higher education institutions over the past two decades (Allen & Seaman, 2013; Allen et al., 2016). The growing use of educational technologies in higher education combined with an increased demand for online courses has reshaped how instructors, students, and technologies interact (Dexter & Richardson, 2019). In March 2020, instructors had to learn new teaching practices to transform their face-to-face classes into online in a matter of weeks (Rupnow et al., 2020). The rapid move to online instruction within the context of biology may have required a more significant change in instructional practice than in other non-science disciplines because of the abstract content and laboratory component (Darling-Hammond et al., 2020). Quality online teaching requires choosing pedagogical practices that help overcome inherent challenges (Darling-Hammond et al., 2020; Scoppio & Luyt, 2017), and the quality of online science learning environments varies among institutions and instructors (Roddy et al., 2017). It is essential to understand how the rapid move to online teaching has shifted biology instructor's perceptions of their teaching practices and experiences (Rad et al., 2021; Zuckerman et al., 2021). This study will explore two research questions, 1. What were biology instructors' experiences teaching online during the COVID-19 pandemic? 2. What teaching practices did biology instructors sustain after their initial online experience?

**Introduction**

The Internet and educational technologies have changed how information is stored, shared, and communicated (Beil & Brame, 2016; Peat, 2000). Over the past twenty years research has shown an increase in online instruction across many institutions of higher education (Allen & Seaman, 2015). From 2000 to 2012, the percentage of students taking at least one online course increased from 8 to 53.5% (Allen & Seaman, 2015). With a subsequent increase in diverse student populations (i.e. non-traditional students) colleges and universities are creating more online offerings and programs to meet students' varying needs (i.e. flexible class offerings) (Sing & Thurman, 2019). In fall 2019, there were 7,313,623 students enrolled in online courses at degree-granting postsecondary institutions (U.S. Department of Education, 2020). In fact, in 2019 more than 400 universities in the United States offered solely online bachelor's degrees, including degrees in the sciences (McCarthy, 2019). Online instruction is increasing and will likely not go away any time soon.

In this manuscript, "online instruction" is defined as, the facilitation of a course that has been developed to be delivered completely online (Zorfass et al., 1998). In general, there are two types of online learning environments in which instruction takes place, synchronous and asynchronous (Singh & Thurman, 2019). The asynchronous learning environment is structured with flexibility with the student in mind; allowing students to look at class materials anytime they choose, complete work within a given timeframe but on their schedule, and does not include a live video component for interaction with the instructor or fellow students (Lin & Gao, 2020; Littlefield, 2018).

The synchronous learning environment, on the other hand, is structured around live interactions, and students can participate in real-time discussions with both instructor and peers (Lin & Gao, 2020; Littlefield, 2018; Wintemute, 2021). Another type of instruction that is partially online is hybrid instruction. The hybrid-learning environment applies to any instruction where content is delivered both online (synchronously or asynchronously) and at onsite facilities. In a hybrid course at least 50 percent of learning activities is transferred to the online format. The online interactions complement the in-person learning in a hybrid classroom format (Bennett et al., 2017).

Online instruction offers a different way for instructors and students to interact and create learning environments that remove the barriers, for example, location and travel (Dhawan, 2020; McBrien et al., 2009). The quality of online instruction varies across institutions and instructors (Knight et al., 2007; Lackey, 2011). Researchers have identified helpful techniques and techniques to support online instruction and increase its quality such as providing online content resources, professional development for instructors in online instruction, and peer support networks (Bailey & Card, 2009; Giesber et al., 2014; Lackey, 2011). However, not much is known about the effectiveness of the described techniques for translating to effective teaching practices in online instruction. The question that arises is having online courses have been implemented with fidelity.

A whole new dimension to online instruction occurred in March 2020, when an infectious virus spread across the world, COVID-19. Coronavirus was identified in December 2019 as SARS-CoV-2 as a respiratory illness. In March 2020, COVID-19 has

declared a global pandemic (hopkinsmedicine, 2021). In response to a global pandemic, many face-to-face higher education classrooms transferred to online environments in a couple of weeks (Dhawan, 2020). Many instructors who had never taught online before were not only expected to transition face-to-face courses to online formats, but also ensure that those courses were taught with fidelity.

When higher education institutions transitioned online, some instructors were provided a week or more to adjust their curriculum, and some instructors experienced a more significant delay due to a lack of institutional resources and online platforms (Walsh et al., 2021). Many institutions lacked access to professional development as well as time for instructors to convert their face-to-face courses to a digital platform in a way that supports best teaching practices online (Crawford et al., 2020). To properly develop an online course it takes months to consider delivery methods, develop student assessments, and learn how to engage in online pedagogy (Crawford et al., 2020; Hodges et al., 2020). Lack of time, and resources as well as the instructor's inexperience made the rapid transition to online instruction a huge challenge (Zuckerman et al., 2020). As a result, studies have shown that the rapid shift to online learning failed to incorporate best teaching practices and pedagogical techniques because instructors were not provided the time or resources to match the effectiveness of their in-person instruction (Hodges et al., 2020; Walsh et al., 2021).

The experiences of the pandemic have created questions for instructors, students, and policymakers, offering a catalyst of change. The pandemic has allowed instructors to reflect and think critically about their curriculum and teaching practices, highlighting

both deficiencies and strengths (Hodges et al., 2020; Rapanta et al., 2020). Instructors now have the opportunity to create a more relevant curriculum that supports authentic learning (Crawford et al., 2020). After the moment of crisis, colleges and universities should continue to think carefully about online learning and the use of educational technologies (Selwyn, 2020). Moving forward, we now have the opportunity to recreate how to deliver content online (Davis-Berg & Kocot, 2021). This research focused on biology instructors' online teaching experiences during the pandemic, institutional support, and personal reflections on current and future teaching practices online or in person. The following section reviews research that explored online undergraduate biology courses before the COVID-19 pandemic.

### **Online Undergraduate Courses in Biology**

It is important to investigate online biology course delivery strategies because online biology courses are becoming a part of a growing course offering in undergraduate education (Biel & Brame, 2016). A growing number of students are now opting for online classes because they find the traditional classroom modality restrictive, inflexible, and impractical (Paul & Jefferson, 2019). Online biology courses that use educational technologies (i.e. multimedia, simulations), are improving education by engaging students through interactive learning experiences (Makransky et al., 2019). Innovative approaches such as instructional online videos (Langfield et al., 2018), digital self-learning tools (Rinaldi et al., 2017), video feedback (Donkin et al., 2019), and social media elements (Maske et al., 2018), have been successful educational technologies used in online biology courses. Studies have shown that by using educational technologies, biology instructors can reduce the cognitive load for students and help students better

retain information and integrate new concepts with their existing knowledge (Chudler & Bergsman, 2014; Domagk *et al.*, 2010; Goff *et al.*, 2017; Mayer, 2008). However, if not implemented effectively educational technologies are not as beneficial. Careful planning, good pedagogical practices, and appropriate resources are necessary when implementing educational technologies in online settings (Englund *et al.*, 2017).

In addition to effective implementation of educational technologies, another common barrier to offering biology classes online is hands-on-lab experiences (Kennepohl & Shaw, 2010; Jeschofnig & Jeschofnig, 2011; Simcock *et al.*, 2017). In biology, many of the labs are centered on hands-on exploration and dissection of specimens to study topics of diversity, cell structure, and function. Creating the hands-on experiences described above online has been especially challenging for biology instructors because some techniques (i.e. pipetting, microscope use) can be challenging and not authentic when transferred online (Lashley *et al.*, 2020; Procko *et al.*, 2020). Several alternatives exist to overcome this obstacle, including online virtual or simulated laboratories and laboratory videos (Beil & Brame, 2016; Kumar *et al.*, 2018). Although virtual labs can be useful in many educational contexts, studies have shown that students noted that virtual labs sometimes take more time to complete (Lyall & Patti, 2010), which may be due to the lack of student-to-student and student-to-instructor interaction that is necessary for guidance and clarity (Kennepohl, 2007). One way to overcome the lab barrier for biology students is to offer a hybrid option. In a hybrid course, students can fulfill the laboratory requirement of biology courses face-to-face while engaging with

other course content online. It is unclear how often a hybrid biology course is an option for students (Gonzalez, 2016; Varty, 2016).

The landscape of online biology courses offered differs by institution and major offerings (Gonzalez, 2016; Varty, 2016). There are many online biology course options for non-majors (i.e. Anatomy & Physiology) compared to biology major courses (i.e. Microbiology). Online courses offered for students who are non-majors (i.e. nursing majors) are three times as common as those intended for biology majors (Varty, 2016). Some factors that contribute to this difference are that non-major courses have larger enrollment sizes, and a higher average of non-traditional students might select online courses to accommodate schedules (Gonzalez, 2016). Studies have shown that community colleges offer more online biology courses than four-year universities because of their high pre-health student population (Garman & Good, 2012). These findings suggest community colleges have responded to the changes and demands for more online biology course offerings (Garman & Good, 2012; Gonzalez, 2016; Hsu, 2021; Varty, 2016). Institution administrators need to evaluate the online biology course options and create a plan to accommodate student needs.

In summary, this body of literature focuses on the landscape of online undergraduate biology courses before the COVID-19 pandemic. There are some deficiencies in online biology courses, which include: a lack of online course options for biology majors, lab options, and a synchronous component for student-to-student and instructor-to-student interaction (Gonzalez, 2016; Kumar et al., 2018; Varty, 2016). These potential barriers described above are limiting the online offerings in biology. Addressing the barriers would create more opportunities for students that prefer or

require online education to study biology (Varty, 2016). One way to address the barriers in online biology courses is to provide instructors with resources and professional development focused on best online teaching practices and related educational technologies (Fish & Wickersham, 2009; McGee & Reis, 2012). Addressing this barrier could increase student access to online learning opportunities in biology and potentially promote student diversity and increase departmental enrollment. The following section reviews research that examined the experiences of students and instructors teaching biology online during the pandemic.

### **Teaching Biology Online During Pandemic**

In March 2020, a barrier was the nature of biology abstract content and hands-on laboratory components that are easier to implement in face-to-face settings (Darici et al., 2021; Tera et al., 2020). This abrupt transition online was a unique experience for students, instructors, and administration (Delgado et al., 2021). Currently, many studies focused on student experiences during the COVID-19 pandemic and not many that focused on instructors' and administrators' experience teaching higher education biology. In what follows, I summarize what we know about student and instructor experiences.

#### *Students Experiences*

According to Reinholz et al. (2020), the rapid shift to online instruction had a significant impact on biology students' classroom participation. Researchers used the EQUIP observation protocol to track biology students' online participation in an introductory biology course. Through EQUIP data analysis researchers found that students' class participation decreased over the semester. When looking across

demographics, there were no patterns between groups (i.e., gender, race). Driessen et al., (2020), used an open-ended survey that asked about students' study habits during online instruction during the pandemic. Student responses revealed that there was a negative impact of emotional factors on study habits. For example, increased anxiety, and lack of motivation impacted students' study habits (Driessen et al., 2020). There were also issues of inequities amongst students. For example, access to technology, financial stability, and caring for family members impacted students' ability to study and learn material due to the varying distractions. Another survey study aimed to describe student experiences learning biology online during the global pandemic (Masiah & Primawati, 2021). With a sample size of thirty-three students enrolled in a biology education course, data shows that 6% of students felt comfortable learning biology online because of the time flexibility and learning environment. On the other hand, 91% of students stated they were unhappy with learning biology online because of the unstable Internet, and the need for face-to-face interaction (Masiah & Primawati, 2021).

Zuckerman et al. (2020) compared course grades and student perceptions of their learning experiences in introductory biology courses in fall (face-to-face) and spring (fully remote) semesters. Results indicated that student course grades increased overall during remote learning, however, researchers hypothesize instructors may have changed their grading practices to balance that challenges students faced learning in crisis (Zuckerman et al., 2020). Additionally, Spring 2020 semester students reported a significant decrease in the number of opportunities for peer interaction and social support. In line with Zuckerman et al. (2020), Supriya et al. (2021) examined the impact

of online instruction in the Spring 2020 semester on the grades of students enrolled in-person biology courses compared to the grades earned by students in the fully online biology courses at the same institution. Researchers also surveyed in-person instructors to understand if assessment practices were changed when the course was moved online. Supriya et al. (2021) results suggest that both online and in-person students received similarly higher grades in Spring 2020 compared to previous semesters (Spring 2018, 2019). Instructors that transitioned their courses online reported they made changes to their course assessments, which may have offset some of the reliability of comparison between course grades (Supriya et al., 2021). Students who were in-person and transitioned online reported negative impacts on their learning, fewer interactions with peers and instructors, and they did not feel a part of the campus community. Women specifically reported a more negative impact on their learning compared to men.

Overall, these findings suggest that remote teaching in crisis may have negatively affected student-learning environments in ways that may not have been captured by grading practices. Masiah & Primawati (2021) and Driessen et al. (2020) results suggest an evaluation be conducted on instructors to support the achievement of students learning biology online beyond the pandemic.

### *Instructor Experiences*

Studies that focused on biology instructors' experience with emergency remote teaching collected mostly survey data (Delgado et al., 2021; Walsh et al., 2021). Walsh et al. (2021) conducted an open-ended survey that asked questions about moments that stood out to biology faculty while teaching online in Spring 2020, difficulties

encountered and any unexpected benefits they received during that semester. Results indicate differences in responses between faculty who were inexperienced versus experienced with online instruction, as well as faculty who participated in professional development and faculty who did not participate in professional development related to online instruction (Walsh et al., 2021). Biology faculty that taught online before the pandemic were categorized as ‘experienced’ and biology faculty that did not teach online before the pandemic were categorized as ‘unexperienced.’ Experienced online instructors described an act of kindness in their shared reflections, for example, faculty stated, “working with a student who was finishing class in her grand- mother’s iPhone because it’s all she had. I was impressed with her dedication” (Walsh et al, 2021, p. 5). However, experienced faculty were likely to include negative student behavior as a challenge during online instruction. Unexperienced biology faculty were the only instructors who included student engagement as a difficulty and described a negative, discouraging memory (Walsh et al., 2021). Findings suggest underlining importance of professional development to help improve student engagement in an online learning environment (Walsh et al., 2021).

Delgado et al. (2021) surveyed cell biology faculty that taught online during the pandemic. The participants found remote teaching to be difficult, but also a valuable experience. Participants reported spending double the amount of time to prep for their remote cell biology labs, but students were still able to learn important scientific skills, which can be applied in their future science courses (Delgado et al., 2020). Researchers also included a manual that incorporates cell biology lab descriptions, learning outcomes,

skills learned, lab setup and format, virtual tools used, lab sources, and lessons learned by the instructors (Delgado et al., 2021).

Previous studies have primarily focused on students' perception of online instruction post-pandemic, but few studies evaluated faculty perception of online instruction post-pandemic in biology. Given the number of students who are currently engaging in online courses and the likelihood of online courses becoming more common among institutions of higher education, it is important to understand the landscape of online biology course offerings and the instructors that teach those courses (Mohammed et al., 2021). The literature that explored biology instructors' experiences teaching online during a pandemic used survey analysis. Additional analysis (i.e. interviews) would be beneficial to support prior claims and get a detailed perspective of instructors' experiences teaching during the pandemic.

This study provides a unique approach to exploring biology instructors' experiences teaching online during the COVID-19 pandemic, in that it goes beyond the pandemic period and connects instructors' current teaching practices. To unpack biology instructors teaching experiences, what they learned, and how the experience impacted their current teaching practices.

### **Research Questions**

1. What were Biology instructors' experiences teaching online during the COVID-19 pandemic?
2. What teaching practices did biology instructors sustain after their initial online experience?

## **Analytical Framework**

### *Teacher-Center Systemic Reform (TCSR) Model*

We used the Teacher-Centered Systemic Reform (TCSR) Model as the analytical framework for this work (Gess-Newsome et al., 2003; Woodbury & Gess-Newsome, 2002). The TCSR model of educational reform recognizes the relationship between instructors' ways of thinking, their backgrounds and classroom practices, and the contexts of their work as the critical influences on instructional improvement and reform efforts. The TCSR Model was initially created to assist in developing and evaluating reform initiatives in K-12 settings (Woodbury & Gess-Newsome, 2002). Gess-Newsome et al. (2003) also used the TCSR model in a higher education setting to analyze factors that facilitated or impeded the reform process for science instructors (Gess-Newsome et al., 2003).

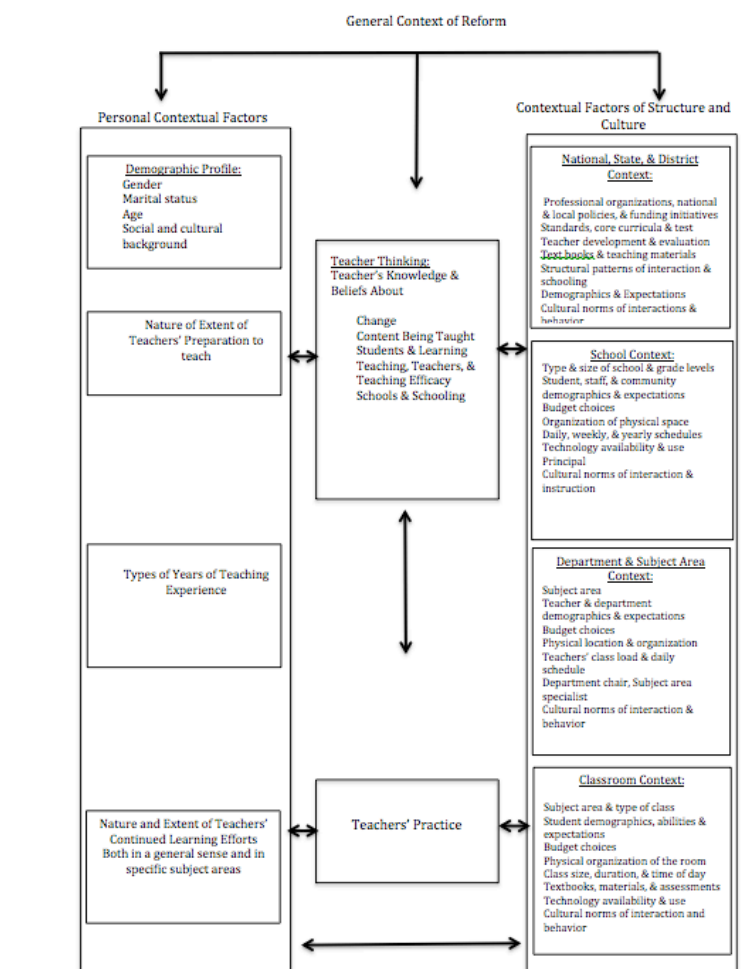
The instructor is the central theme in the TCSR Model because they implement teaching practices in the classroom. The TCSR Model emerged from the incorporation of several contextual factors that can influence the experience of teachers involved in reform or change efforts. At the classroom level considerations can include issues that may arise from the organization of classroom space, materials used, and the types of interpersonal interactions that occur between students and teachers (Enderle et al., 2013). The model also incorporates other personal factors that shape the central role of an instructor, including years of experience in teaching and career stage. At the department level, the model could include types of administrative support an institution offered, the culture

among colleagues, and course scheduling logistics. Additionally, administrative actions, institutional support, and relationships among faculty can serve as key components for understanding the trajectory of change efforts. The broader cultural context can be evaluated by the impact of professional organizations, goals for higher education institutions, and resources. The instructor's perception of their response to contextual factors highlights those of importance to them. The TCSR Framework is relevant to this study because changes occurred because of the pandemic. The Framework helps consider what factors contributed to instruction due to the shift online (See Figure 4-1).

More recently, Rupnow et al. (2020) used an abbreviated version of the TCSR Model (See Figure 4-2) to investigate six Chemistry tenured faculty instructional practices during the COVID-19 pandemic. Researchers found that faculty adapted quickly to institutionally offered platforms, but modified their courses as minimally as possible (Rupnow et al., 2020). Participants also struggled with assessment and held differing beliefs about students and teaching. The implications of these findings recommend similar studies to ascertain current faculty beliefs and instructional practices in other departments to identify shared visions for change and effective support for enacting that change (Rupnow et al., 2020).

Figure 4-1

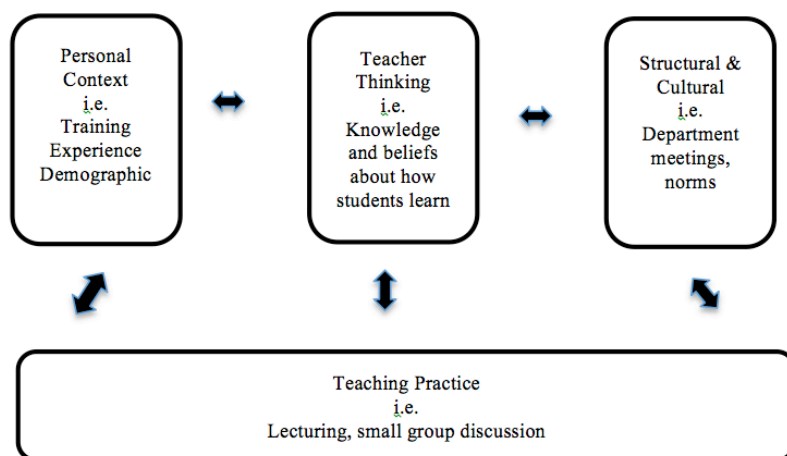
*Teacher-Centered Systemic Reform (TCSR) Model*



*Note.* Adapted from: Overcoming the paradox of change without difference: a model of change in the arena of fundamental school reform. Educational Policy, Woodbury, S., & Gess-Newsome, J., 2002

**Figure 4-2**

## Teacher-Centered Systemic Reform (TCSR) Model



*Note.* Abbreviated version of the TCSR Model. Examples of each factor are included but not comprehensive of each category. Adapted from: A perturbed system: How tenured faculty responded to COVID-19 shift to remote instruction, Rupnow, R., LaDue, N., James, N., 2020

In the context of this study, TCSR Model is used as the analytical framework because implications from previous research (Rupnow et al., 2020) findings suggest the TCSR model captured faculty beliefs about their teaching practices during the pandemic and what changes occurred. We believe the TCSR Model is suitable to interpret biology instructors teaching practices and experiences online during and after a global pandemic for comparative results. The study provides a unique approach to identifying contextual factors that contributed to the experiences of biology instructors (i.e. tenure-track faculty, graduate teaching assistants) teaching online during a global pandemic. Previous studies with tenured faculty highlighted some aspects of these factors (Rupnow et al., 2020; Walsh et al., 2021) and we want to compare our findings to identify similarities or

differences with a variety of instructor types (i.e. GTA, Post-Doc).

## **Methods**

### **Sampling Procedures & Recruitment**

A previous research study (See Chapter 3) was used to select interview participants for this study (see more detail below). This was a purposeful sampling procedure to recruit participants that could give in-depth or detailed information about teaching during the pandemic and their new and planned future teaching practices (Patton, 2002). In addition to educational technology knowledge and teaching experience online during a global pandemic, it was important to note the availability and willingness of participants to communicate their experiences and opinions (Bernard, 2002). The deliberate choice of an instructor to participate due to their experience teaching biology online during a pandemic was a key component in this sampling process. We believe this selection process allowed a variation of responses and different or similar lived experiences of biology instructors teaching online during a pandemic. From this purposeful sampling procedure,  $n=9$  responded with full commitment.

Before being selected for this study, participants were recruited to complete a cross-sectional survey. We recruited participants through the National Association for Research in Science Teaching (NARST), the Society for the Advancement of Biology Education Research (SABER), Biology Teaching Assistant Project (BioTAP) listservs, and personal networks. The participants for this study were post-secondary biology instructors (i.e., tenured professors, non-tenured professors, and graduate teaching assistants) at two and four-year higher education institutions across the United States.

Participants had to be actively teaching an undergraduate biology gateway course (e.g. general biology (majors), introductory biology (non-majors); taught online during the COVID-19 pandemic; and have at least one semester of teaching experience with educational technology (e.g. computer simulations, video animations, software). The various organizations and institutions allowed us to recruit participants from diverse educational backgrounds with a variety of different perspectives and experiences, all of who taught gateway introductory biology courses.

### **Data Organization**

Each interview lasted approximately 45-60 minutes. Interview data was organized before analysis in three stages. First, audio-recording files from Zoom were saved and indexed, and anonymized according to numerical code. Second, audio recordings were transcribed verbatim through the transcript software, otter.ai (2021). Third, all audio files and transcript files were uploaded into Dedoose (2019) to organize, classify, and analyze. Participants were given pseudonyms.

### **Interview Structure**

To understand Biology instructors' experiences teaching online during the COVID-19 pandemic and what teaching practices they sustained, semi-structured interviews were conducted. For the interview protocol, questions were adapted from Rupnow et al. (2020), which, focused on Spring 2020 semester instructional choices, views on student learning, and future instruction. Questions were modified to elicit the experiences of biology instructors teaching online during a pandemic and reflections on what they learned from their experience. Interview questions were organized according to Yin's (2017) levels of questions, which addressed the how and why of the individual

phenomena. More specifically, we asked demographic questions first and then gradually asked more detailed in-depth questions as the interview proceeded. To understand factors that influenced instructors' teaching practices online during and after the pandemic, the interview questions targeted three main topics. The topics included (1) Reflecting on the rapid transition to teaching online (2) Reflecting on pandemic impacts on teaching (3) Reflecting on new teaching practices influenced by experiences with online teaching during a pandemic.

Topic 1 addressed understanding how the online transition during COVID-19 impacted instructors' teaching practices. This aligns with the personal context (i.e. personal experiences during the pandemic that impacted teaching), teacher thinking (i.e. instructor beliefs about teaching), and structural and cultural norms (i.e. institutional resources) from the TCSR Framework because these were all possible factors that impacted teaching practice when switching online. Topic 2 addressed if biology instructors teaching practices were impacted by the pandemic, which aligns with teacher thinking (i.e. student learning, beliefs about teaching), and structural and cultural norms (i.e. institutional norms, departmental norms) of the TCRS Framework. Topic 3 provided insight on new ways biology content can be implemented online with educational technologies. This aligns with teacher thinking (i.e. teaching efficacy, change in instruction) and structural and cultural norms (i.e. technology availability, resources) from the TCSR Framework. Sample interview questions with the corresponding topic are in Table 4-1.

**Table 4-1***Three Interview Discussion Topics and Corresponding Interview Questions*

<b>Topic</b>	<b>Samples Questions</b>
(1) Reflecting on Rapid Transition Online	<ul style="list-style-type: none"> <li>• How did you perceive the pivot to online instruction due to the pandemic?</li> </ul>
(2) Reflecting on Pandemic Impact	<ul style="list-style-type: none"> <li>• Are there any classroom activities you once viewed as necessary that you now view as less important or vice versa? What are they? Why?</li> </ul>
(3) Reflecting on New Teaching Practices	<ul style="list-style-type: none"> <li>• What did you learn from Spring 2020 that you will use in your classroom moving forward?</li> </ul>

To obtain item face validity evidence, before the interview being conducted, the questions were piloted with two biology instructors. The instructors taught biology online during the pandemic but were not participants in the study. The pilot interviews were conducted to verify interview questions elicited experiences as intended by the research questions and analytical framework. The current interview questions reflect the final revised version of the protocol (See Appendix D).

**Data Analysis**

The interview responses were coded in two stages: (1) Deductively align biology instructors' past and present teaching practices and experiences with the Rupnow et al. (2020) codebook which aligns with the TCSR Framework, highlighting personal factors (i.e. training, experience), teacher thinking (i.e., beliefs about student learning), and structural and cultural norms (i.e., institutional norms). Rupnow et al. (2020) used a modified version of the TCSR Framework therefore; the codebook might not include all

possible codes (2) Inductively to capture codes that were not in the initial *a priori* codebook.

Each of the  $n = 9$  participants' transcripts was independently coded by two researchers using the initial codebook (See Appendix E) as an *a priori* analytical guide to ensure inter-rater reliability (Rupnow et al., 2020). If a text segment aligned with any of the *a priori* codes (i.e. 24 years teaching) we highlighted that aspect (i.e. personal context-orange). Identified text segments for each of the codes were discussed as a team. If a text segment did not align with any of the *a priori codes* it was set aside during this initial round of coding. If there were any disagreements between *a priori* codes, they were resolved through discussions with the two researchers to reach a consensus. When a consensus was reached for all coded text segments, a total of each of the coded segments was calculated.

After all, transcripts were coded deductively using the *a priori* codebook (Rupnow et al. (2020), inductive coding of the remaining text segments that were not analyzed during the deductive stage were coded. During the inductive coding process, preliminary codes were established based on similar responses by the primary researcher. Preliminary codes with code descriptions were assigned to each participant in a narrative format. Each narrative summary was emailed to the respective participant to confirm accuracy, ensuring their teaching experiences were captured through member checking. Member checking comments helped clarify inductive codes.

Next, comments from the participants' member check were combined with the inductive codes and collapsed to form more salient categories. Codes were then organized in a hierarchical structure allowing for different levels within the coding

scheme (Saldana, 2016). Through the coding process, we recorded emerging ideas through analytic memoing. Finally, the hierarchical data was visually displayed in tables (Saldana, 2016). Each table includes all *a priori* codes, sub-codes, and new codes for each topic area (i.e. Reflecting on Rapid Transition Online) and was summarized.

### **Credibility and trustworthiness**

For qualitative data collection, it is important to establish trustworthiness and credibility for research (Lincoln & Guba, 1985; Mills & Gay, 2016; Morse, 2011; Yin, 2017). Within this study, there are two ways in which trustworthiness was established: (1) Member checks were conducted by emailing narrative summaries of each participant interview to the participant to verify an accurate interpretive meaning of their responses providing validity evidence, and (2) An additional biology education researcher helped code transcripts and compared codes until an agreement was reached providing reliability evidence.

## **Results**

### *Participant Descriptions*

During the interviews, participants were asked to share their academic backgrounds, to elicit their teaching experience and familiarity with online teaching before the global pandemic. Participant descriptions, which include instructor type, years of teaching experience, institution type, and prior online teaching, are provided in Table 4-2. Each participant's name was anonymized with pseudonyms.

**Table 4-2***Demographic Variables for Selected 9 Biology Instructors*

<b>Pseudonym</b>	<b>Instructor Type</b>	<b>Years of Teaching Experience</b>	<b>Institution Type</b>	<b>Prior Online Teaching Experience</b>
Ronda	Tenured Faculty	24	Four-Year Public Institution	No
Ryan	GTA	14	Four-Year Public Institution	Yes
Amy	Tenured Faculty	9	Four-Year Public Institution	No
Eileene	Tenured Faculty	21	Two-Year Community College	Yes
Rachel	Tenured Faculty	7	Four-Year Public Institution	No
Brandon	Post-Doc	6	Four-Year Public Institution	No
Olivia	GTA	5	Four-Year Public Institution	No
Linda	Full-time Lecturer	25	Four-Year Public Institution	No
Leslie	Tenured Faculty	14	Four-Year Minority Serving Institution	No

**Coding Results**

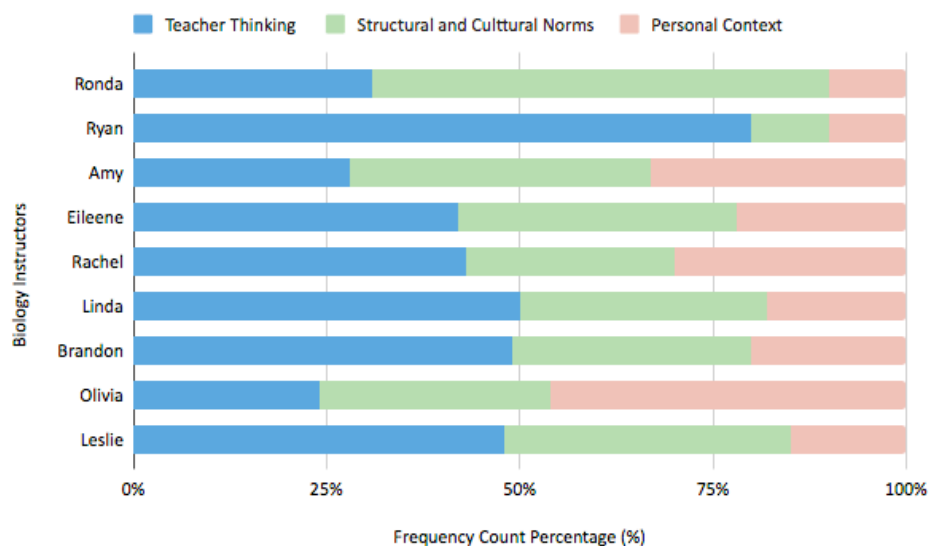
The *a priori* categories used in the initial coding of the transcripts were “teacher thinking”, “personal context”, and “structural and cultural norms”. Rupnow et al. (2020) define “teacher thinking” as the knowledge and beliefs about teaching, students, and content that the instructor has. “Personal contexts” are factors that are associated with instructors’ professional lives (i.e., teaching experience) that may impact how they teach. “Structural and cultural norms” is a category that exists at multiple levels. For example, at the department level, norms could include types of administrative support an institution offered, the teaching culture among colleagues, and/or course scheduling logistics.

Additionally, administrative actions, institutional support, and relationships among faculty can be considered structural and cultural norms.

To provide an overall landscape of how often participants discussed a specific code category (i.e., personal context) we created a graph that shows the percentage of times an instructor mentioned a given category or gave an example that reflected a category. Figure 4-3 below highlight the three factors from the TCSR Framework (Rupnow et al., 2020) through which instructors' experiences were similar to the Framework descriptors. There were variations among instructors' experiences. Less than half of the instructors (n=4) talked about teacher thinking the most and more than half the instructors (n=6) talked about the personal context the least.

**Figure 4-3**

*Percentage of Frequency Counts per Code by Instructor*



### **Biology instructors' experiences teaching online during the COVID-19 pandemic**

To address how biology instructors' experiences with teaching online during a pandemic occurred, one topic (i.e. Reflecting on Rapid Transition Online) is discussed.

Below we provide a detailed explanation of each of the resulting codes and the corresponding coding chart. We highlight factors that influenced instructors' teaching practice using the three categories of the TCSR Model (i.e. teacher thinking, structural norms, and cultural norms) as an analytic frame. The teaching practices of participants were also analyzed. In the results section below, detailed examples of each code aligned with *a priori* codes and new codes are provided.

### ***Reflecting on Rapid Transition Online***

When participants reflected on teaching practices in the beginning of the pandemic (March 2020-May 2020) three factors emerged that were relevant to their experiences teaching online. Instructors reflected on their thinking about instruction, personal context, and structural and cultural norms of their institution (as aligned with the TCSR framework). Participants' responses were representative of each category and described in more detail below. Some codes were modified to better represent the participants' responses. For example, the technological pedagogical content knowledge (TPACK) sub-code was added to teacher thinking to capture participant views on 'Purpose of instruction with technology, the value of various online teaching strategies.' (See Chapter 3 for full Framework description).

**Table 4-3**

*Reflecting on Rapid Transition Online Codes, Sub-codes, Coding Definitions and Examples*

<b>Codes</b>	<b>Sub-Codes</b>	<b>Coding Definitions</b>	<b>Examples</b>
<p><b>Teacher Thinking:</b></p> <p>The knowledge and beliefs about teaching, students, and content that the instructor has.</p>	How are instructors thinking about the impact of rapid transition online	Data was coded with this if they compared the difficulty or effectiveness of teaching online to teaching in person.	“Not a whole lot of learning took place after that. We were just making the students earn points. I mean, you can't just switch like that in a General Biology lab, you know, and think that they're going to get the same thing or even close to the same thing out of it.”
	How are teachers thinking about student engagement.	Data was coded with this if instructors discussed how they engaged with students online.	“I had to create different ways to ask different questions to get them engaged, at least responding in the chat if nothing else.”
	**TPACK: How are teachers thinking about their own knowledge related to pedagogy, content, and technology integration.	*Data was coded with this if instructors gave reasons why they used technology, and discussed the value of different teaching strategies used with the technology.	“And I rewrote some of the lab activities and researched if there were simulations or something that we could grab at the last minute to digitally illustrate what we would have been doing in person Anatomy & Physiology.”
<p><b>Personal Context:</b></p> <p>Factors that are associated with instructors' personal lives and professional lives that impact how</p>	**Online Teaching Experience	**Data was coded with this code if they described their experiences teaching online prior to or during the Covid-19 pandemic.	“that was extraordinarily challenging for a class that does not do well online in any, you know, sort of environment and a

they teach.			science lab, it would be one of those.”
	**Family Dynamics	*Data was coded with this code if instructors talked about their personal lives and how that affected their teaching during the pandemic.	“And personally, I was out with laryngitis, which is evidently transmissible, so I couldn't talk. So I couldn't teach the first week online. And I wasn't supposed to go to work; also taking care of my immune compromised daughter with an unknown virus going around was difficult.”
	People at Institution	Data was coded with this code if faculty or staff were mentioned that helped instructors transfer their courses online.	“I had to take quite a bit of leadership on that. Because I'm one of the course designers for the online A&P course, I had familiarity with how to give students resources for anatomy in that virtual setting.”
<b>Structural &amp; Cultural Norms:</b>  At the department level or administrative norms, (i.e. teaching culture among colleagues, support and relationships among faculty ).	Institutionalized Platforms	Data was coded with this code if their institution or department provided technology or online platforms.	“They gave us they had a page, they called it keep teaching, and it was a resource page.”
	Resources provided or Lack of Resources	Data was coded with this code when the instructors' institution provided no resources. Lack of time to prepare came out in this	“So we, yeah, no, we did not receive any support and they didn't provide anything. I just came up with it because it was fully online. You know, so I just had

		code.	to come up with some curriculum for that.”
--	--	-------	--

*Note.* \*\* Indicates new sub-code added to the codebook, \* Indicates new coding definition added to the codebook.

### *Teacher Thinking*

Some participants reflected on their beliefs about teaching and student learning. For example, Linda [Full-time Lecturer] stated, “Not a whole lot of learning took place after that. We were just making the students earn points. I mean, you can't just switch like that in a General Biology lab, you know, and think that they're going to get the same thing or even close to the same thing out of it.” Other participants reflected on biology content and how that transferred online. For example, Brandon [Post-Doc] responded, “We emailed the students the instructions, like a guided curriculum, including some activities they can do on their own. Students used a link for online labs and they collected leaves outside and identified the leaves.” Some instructors believed labs cannot be transferred online, while other instructors found ways to incorporate laboratory components online.

Olivia [GTA], on the other hand, restructured her course to be accessible online. Olivia stated, “I formatted, the lab Canvas shell to accommodate all components of the course. And I rewrote some of the lab activities and researched if there were simulations or something that we could grab at the last minute to digitally illustrate what we would have been doing in-person Anatomy & Physiology.” Additionally, in Olivia’s reflection TPACK is present when she discussed how and why she would integrate simulations to illustrate concepts in Anatomy and Physiology. Some instructors tried to use the resources provided by their institutions and create an environment where students could

learn, and some instructors were not able to transfer their classes online because of a lack of hands-on opportunities (i.e. general biology lab).

Another theme across instructors' reflections was the value of student-centered activities with educational technologies. Instructors wanted to transfer student-centered activities online; however, it was not as feasible to do in the short time frame they were given to prepare lessons. Reflecting on technology integration Leslie [Tenured] and Ronda [Tenured] used synchronous discussions and breakout rooms to transfer in-person activities to an online context. Leslie reflected on how she had to change the way she asked questions to get students engaged in the content. For example, Leslie stated "to have a discussion on zoom talking to blank screens is different. I used the chat feature a lot and talked to students in smaller breakout rooms. I had to create different ways to ask different questions to get them engaged, at least responding in the chat if nothing else."

Eileene tried to transfer an active learning activity online and it was harder than she anticipated. She responded:

**Eileene** : "I have this really good activity that has gotten great feedback in the past, where I have like, all the different steps cut out and laminated and they're in a little bag and I give them to group students. And it's very kinesthetic because they have to put them in order. And they get to talk to each other about that. That one was extremely hard. And I attempted to try to change that over into a virtual setting. And I don't know that all the students got that. I mean, I tried to explain, hey, you know, print out this sheet of paper and cut the strips and do it yourself and, and then I had like an online module where they could put their answers and I could just tell there was a lot of confusion, that not having me there to help guide them through that experience and putting so much of that on them."

Instructors used discussions to get students actively engaged online. Another instructor tried to mimic in-person lesson online and it did not transfer over well. The

next section highlights personal context that reflect the rapid transition to online instruction.

### *Personal Context*

Personal context also contributed to participants' teaching practices and experiences. A persistent theme that reflected personal context during the time of transition online was that instructors felt it was a challenging time for themselves and their institutions to navigate the change due to the speed at which the transition occurred. Ryan [GTA] stated, "Spring 2020, there was like everybody else it was people running around with their heads cut off trying to figure out just to get through the end of the semester." Similarly, Leslie [Tenured] response was, "essentially our institution gave all of the faculty three days to go from in-person to online. And it had gotten to the point where there had been lots of concerns." Additionally, Linda [Full-time Lecturer] stated, "that was extraordinarily challenging for a class that does not do well online in any, you know, sort of environment and a science lab, it would be one of those." Ronda [Tenure Faculty], on the other hand, felt the transition online was painful, but not as challenging as her colleagues because of her technology background. Ronda stated, "So it was a very rapid and very painful transition. I think it was a little bit less painful for me, just because I felt a little more comfortable with technology." The transition was challenging for some participants because of preparation time and the context of the course.

Another factor from the personal context that was reflected on by instructors was outside factors that influenced their classroom teaching. For example, Ronda [Tenured] discussed contracting an illness and taking care of her immune-compromised daughter as factors that contributed to her teaching effectiveness. Ronda

stated, “And personally, I was out with laryngitis, which is evidently transmissible, so I couldn't talk. So I couldn't teach the first week online. And I wasn't supposed to go to work; also taking care of my immune-compromised daughter with an unknown virus going around was difficult. So my class had to start off asynchronously instead of synchronously because of my circumstances.”

Instructors also discussed personal factors that might influence student learning. For example, home environment, family dynamic, and access to the Internet could impact student learning. Amy [Tenured] stated, “But, like yeah, so many students just had, they were they were working or I mean, we mostly have traditional age students but we have like a few adults that have returned that have kids. And you know, I have a toddler myself.” Similarly, Leslie [Tenured] stated, “And in this time of much chaos, where the students weren't sure what was going on. And some of them had very big network issues, or gee, I've tried to share this computer with my three siblings all of that. And I didn't understand the level of chaos that my students were dealing with.” Family dynamics, working from home, and empathy for students played a key role in teaching practice during the pandemic. After reflecting on the initial transition to online teaching participants discussed how they taught for the remainder of the Spring 2020 semester. For example, Olivia [GTA] took time to research ways to get students to engage with the content. Olivia responded, “And so they had problem based learning case reports. So they were working through a patient profile and trying to make a diagnosis. And so they had time to do that in their group channel, or via chat if they didn't have video.”

*Structural & Cultural Norms*

Participants who had experience teaching online before the pandemic were called on to take leadership roles in their departments and to provide guidance and resources to their colleagues. For example, Eileene [Tenured] stated, “I had to take quite a bit of leadership on that. Because I'm one of the course designers for the asynchronous online A&P course, I had familiarity with how to give students resources for anatomy in that virtual setting.” Additionally, Ryan [GTA] stated, “I started as a TA in an online course, so I helped faculty transfer their classes online asynchronously.” Eileene and Ryan’s examples demonstrate that institutions asked experienced online instructors to assist in the transition to online instruction for their departments. In both instances the instructors had experience with asynchronous online instruction, but not synchronous online instruction.

Instructors also reflected on the structural context they were teaching in when discussing resources provided by their institutions to prepare for the transition to online teaching. Some institutions provided a lot of different resources (i.e., learning management system support, online simulations) and some institutions did not provide any resources. Ronda [Tenured] mentioned a resource page that was given to faculty to help with online teaching. Ronda stated, “They gave us they had a page, they called it keep teaching, and it was a resource page. And it had information on various strategies to use for running Zoom meetings effectively.” Similarly, Rachel’s [Tenured] Department chair sent out a spreadsheet to collect resource ideas to provide for instructors in the biology department. More specifically, Rachel responded, “the department chair just like sent out a spreadsheet being like, okay, like, what do you need for every class, but we

didn't really know what we needed yet.” Also, Rachel mentioned the teaching and learning center sent out a bunch of links about how to teach effectively online. Some institutions provided a resource page for instructors, however, they were not as effective without additional training on how to use the suggested resources.

Instructors also reflected on the lack of resources and support from their institutions during the rapid transition to online instruction. Brandon [Post-Doc] and Olivia [GTA] both stated their institutions did not provide them with any resources. Similarly, Linda stated she had to come up with her way to transfer her course online. Linda [Full-time Lecturer] reflected, “So we, yeah, no, we did not receive any support and they didn't provide anything. I just came up with it because it was fully online. You know, so I just had to come up with some curriculum for that.” Participants had varying experiences with resources and support provided by their institutions, but collectively instructors believed the rapid transition to online instruction was challenging due to the number of resources they received and the time they were given to prepare for their courses.

Instructors reflected on teaching with technology, and the value they placed on various strategies. Some strategies did not translate well in the online setting at the beginning of the pandemic because of a lack of preparation time, resources, and training. In the section below we discuss the overall impact if any the pandemic had on instructors.

### **What teaching practices did biology instructors plan to sustain**

To address what teaching practices biology instructors sustained after the pandemic, two topics (i.e. Impact of Pandemic, Future Teaching Practices) were isolated,

thematized, and condensed into coding charts. Below we describe a detailed explanation of each of the resulting codes and corresponding coding charts.

### ***Reflecting on Pandemic Impact***

After the Spring 2020 semester, instructors had time to think about their experiences and if they impacted their teaching and student learning. Teacher thinking was a persistent theme that was reflected upon by instructors. Participants' responses representative of each topic is described in more detail below. Some codes were modified to better represent the participants' responses. For example, the sub-code views on instruction were added to explore 'practices employed by instructors, capturing their reflection on instruction during the pandemic.'

**Table 4-4**

### *Reflecting on Impact of the Pandemic Codes, Sub-Codes, Coding Definitions and Examples*

<b>Codes</b>	<b>Sub-Codes</b>	<b>Coding Definitions</b>	<b>Examples</b>
<b>Teacher Thinking</b>	Teacher thinking about having empathy for students	Teacher notes concern for student needs in an online classroom, preferences, and challenges.	"It was maybe like the pandemic generally just because everything was so chaotic. It made me I think a little bit more compassionate."
	Student-faculty communication	Importance/value of communication, feedback between student and instructor.	"But I think what I learned is that I could reach more students online, then I can in person. And that I have the know how."
	**Views on Instruction	*Practices employed by instructors. Reflection on instruction during the	"And some of the things that I was a little hesitant to try doing, I've

		pandemic	now tried. And there were little hiccups, some worked a little better than others.”
--	--	----------	---

*Note.* \*\* Indicates new sub-code added to the codebook. \* Indicates new coding definition added to the codebook.

### *Teacher Thinking*

Some instructors' views about their teaching changed. For instance, Amy [Tenured] became more compassionate, and flexible after teaching Spring 2020. Amy stated, “It was maybe like the pandemic generally just because everything was so chaotic. It made me I think a little bit more compassionate. You know, I thought of myself as like a pretty like easygoing, compassionate instructor in the past, but the pandemic made me even more compassionate. And so it just made me I think, more willing to be flexible.” Ryan [GTA] also reflected on being more compassionate and empathetic towards students. Ryan stated, “I also saw students did not have the access that I thought they would. You know, so we had, we had students who were using their phone, only to access, which makes it really difficult to take an exam that requires you to use the phone as a camera. And I hadn't really considered that previously, you know, we just kind of assumed. So rethinking about student access has been something on my mind now.” Both Amy and Ryan became more empathetic towards students.

Ronda [Tenured] also felt like she learned a lot during Spring 2020 and tried teaching strategies that she never tried before. Ronda responded, “Absolutely, I've learned a ton. And some of the things that I was a little hesitant to try doing, I've now tried. And there were little hiccups, some worked a little better than others.” Similarly,

Olivia [GTA] was nervous about how her course would translate online but was pleasantly surprised by how well it worked. Olivia stated, “I was afraid that maybe I wouldn't translate well, online. I teach in a pretty animated way. And I was afraid it was just gonna look dorky online. But I think what I learned is that I could reach more students online, and then I can in person. And that I have the know how.” Olivia also expressed that she would like to find training opportunities to continue to develop skills to teach online.

Brandon [Post-Doc] did not prefer teaching online during the pandemic, but it made him appreciate in-person teaching more. Brandon stated, “So I think when I go back to in person, I really appreciate more, learning is also emotional, social, and the students need to be motivated. And, the teacher-student relationship is very critical. I now feel more motivated to teach.” Similarly, Ronda [Tenured] did not enjoy teaching online, but believed the pandemic helped her grow as an instructor. Ronda responded, “So you know, and that was coming out of the pandemic, I think it helped me grow, which was great. “Participants had differing feelings related to teaching online, however overall they grew as instructors by becoming more proficient by adding things to their teaching toolbox.

In contrast, some instructors believed that the pandemic did not have much impact on their teaching. More specifically, Linda [Full-time Lecturer] felt like the pandemic did not impact her teaching at all. Linda responded, “I would say it doesn't really have an impact of my view of myself as an instructor or the way I teach. I mean, not that I was always happy with it. In fact, I was very frequently unhappy with it. But it wasn't a

choice I made. It was something that happened and I will go back to my same way of teaching.”

Participants reflected on a variety of ways they think about their teaching after the pandemic. Some instructors developed compassion and empathy for students, while other instructors found ways to deliver content online. Other instructors did not think the pandemic impacted their views about teaching and learning at all. In the next section we discuss new and revised teaching practices instructors sustained after the pandemic.

### ***Reflecting on New Teaching Practices***

During Fall 2020 some of the factors that contributed to participants’ teaching practices changed. Factors that contributed to participants teaching practice included structural and cultural norms and teacher thinking. Within the context of teacher thinking, participants reflected more on their TPACK when describing integrating technology into their teaching, and instructors reflected on the interplay between content, pedagogical and technological knowledge. We highlight factors that influenced new teaching practice using the three factors of the TCSR Model (i.e. teacher thinking, structural and cultural norms), and the teaching practices an instructor used with educational technologies giving detailed examples of each.

**Table 4-5**

*Reflecting on New Teaching Practices Codes, Sub-codes, Coding Definitions and Examples*

<b>Codes</b>	<b>Sub-Codes</b>	<b>Coding Definitions</b>	<b>Examples</b>
<b>Teacher Thinking</b>	Discontinued instructional practice	Teaching practice not retained after the pandemic.	“So I personally don't think I would ever give a paper exam again.”
	New Instructional Practice	Teaching practices retained after the pandemic.	“I realized how, like, I discarded how many, just directly memorization questions I had on my exams. So now that we're in person, I let everybody bring a sheet of paper to the exam, filled out double sided, whatever they want. And I like that, because I kind of realized how much cumbersome memorization was required. That isn't that valuable.”
			“My class is now kind of a hybrid format. I have all of these narrated PowerPoint slide videos now. And that it is helpful for students who struggle to take notes. PowerPoint are now always available, students can always go back and watch that and get the content on a schedule that works for them.”
	**TPACK: How are teachers thinking about their own knowledge related to pedagogy, content, and technology integration.	If instructors gave reasons why they used technology, and discussed the value of different teaching strategies used with the	“the students did DNA experiments and PCR analysis using virtual labs to see the structures, they clicked and followed steps.”

		technology is was coded for this code.	
<b>Structural &amp; Cultural Norms</b>	Institutionally provided professional development	If instructors reflected on training available by institution or future training they want to attend through institution it was coded for this code.	“Also through the summer professional development I learned how to integrate interactive simulations on D2L, and also learned how to do backwards planning. I will be using what I learned in future online classes.”

*Note.* \*\* Indicates new sub-code added to the codebook, \* Indicates new coding definition added to the codebook.

### *Teacher Thinking*

When participants reflected on Fall 2020, they discussed new ways to teach with educational technologies, ways they communicate with students, and the purpose of assessment. Ronda [Tenured] talked about how she now teaches her class in a hybrid format and the role of educational technologies in her courses. Ronda stated, “My class is now kind of a hybrid format. I have all of these narrated PowerPoint slide videos now. And that it is helpful for students who struggle to take notes. PowerPoint are now always available, students can always go back and watch that and get the content on a schedule that works for them.” Similarly, Brandon [Post-Doc] wants to setup his class in a Hybrid format, but for differing reasons. Brandon stated, “I’m a special case, because uploading PowerPoint is kind of made it easier for me, because giving a lecture in English teaching science, biology is kind of intimidating for me, because to prepare for an oral lecture it takes so much time for me. But the hybrid structure, I can show up, answer the questions, and I enjoy the interaction.” Creating a hybrid format for courses allowed instructors to

provide the content before class and use class time to answer questions and do active learning activities.

Instructors re-evaluated the way they created and gave assessments. Brandon [Post-Doc] started providing students with study guides for exams, he stated, “I like to provide the detailed guide, like the study guide for them. I think that’s important.” Leslie [Tenured] switched from closed-book exams to open book exams. Leslie stated, “I realized how, like, I discarded how many, just directly memorization questions I had on my exams. So now that we're in person, I let everybody bring a sheet of paper to the exam, filled out double-sided, whatever they want. And I like that because I kind of realized how much cumbersome memorization was required. That isn't that valuable.” Rachel [Tenured] also started to give open-book exams, and she transferred all her assessments online. Rachel stated, “I definitely like giving the exams online. And I like having exams be open book. I don't see the point of having closed book exams like never in my life as a scientist, am I like shut in a room with no resources to answer a question, right?” Ronda [Tenured] also discussed how she completely changed the way she gave exams and created exam questions.

Ronda: “I completely changed the way I do exams and quizzes. Thing one is, I took out I replaced the word exam with the word quiz because it seemed like my students just in general, after March of 2020, their anxiety levels went through the roof. And they have told me in the past, quizzes are less scary than exams. And I no longer have anything cumulative because I don't feel like cumulative is necessary. I also broke each quiz into two sections, a smaller section that I called the fact check, which is like low level Bloom's the remembering, understanding flashcard level knowledge. The second section is focused on critical thinking and problem solving skill questions. All exams are now given online.”

Ryan [GTA] also gave all his exams online, he stated, “So I personally don't think I would ever give a paper exam again. I think that I would do them exclusively online. In

a class of 100 people, the whole process can just be done easily in an online setting.”

Participants designed questions that allowed students to think critically.

Instructors learned a lot about creating exams online and will continue to give online exams and quizzes through their institution’s learning management system or open book in-person exams.

Instructors also reflected on how they integrated technology into their teaching beyond the Fall 2020 semester and the challenges or affordances of the integration. For example, Rachel [Tenured] reflected on developing an animal behavior lab from observing a beta fish in-person to an online lab that observed a variety of animal behaviors using an interactive simulation. More specifically Rachel stated, “I developed like an interactive way students could observe the behavior. It's called an ethogram and animal behavior, when making observations, students could use a microscope to see small things up close, a scale to measure weight, or a thermometer to determine changes in temperature.” Brandon [Post-Doc] also reflected on how he integrated online lab simulations, “the students did DNA experiments and PCR analysis using virtual labs to see the structures, they clicked and followed steps.” Rachel and Brandon both used lab simulations but in different ways. Rachel used the lab simulation as a student-centered activity and Brandon used the lab simulation to visualize content.

Other instructors reflected on how they used Zoom to integrate activities online. For example, Ronda [Tenured] described an activity she did on Zoom that she will incorporate in future classes.

Ronda: “So there's one that works really well that I will include when we move to in-person for species interactions when we were doing ecology. Online, we used Rock-paper scissors for species interactions, and they kept getting sent into breakout rooms, and they

do rock paper, scissors with each other, and then they'd come back, and we'd track, I'd have a Excel spreadsheet that I would plug the numbers into and show them how the graph was changing as that was going through. The students loved it. And it helped them they seem to understand species interactions, how they're not always negative. We will continue to do that on Zoom for one of the Hybrid components.”

Brandon [Post-Doc] also plans to use Zoom breakout rooms to incorporate study groups for his classes. Brandon stated, “for students who have crazy schedule with the kids, their work, and if they live far away. Especially those people they probably live in the house if far away from campus, but they still need the community online Zoom study groups could be a very convenient way to have a consistent learning partner to hold you accountable.” Both participants found ways to make instructional technology, interactive educational technology for students to engage with the content. In addition to Zoom, Brandon also wants to continue using D2L to have weekly discussions. Brandon responded, “I think because some students are so good at social media like posting and they are probably more comfortable asking questions online in their chatting group. So that gives them another option to work in small groups in an online discussion.”

Instructors thought about how to integrate technology into their lessons and create an online environment that was easily accessible to students by putting everything in one place, the learning management system that can be accessed on all electronic devices (i.e. cell phones, laptops).

### *Structural & Cultural Norms*

Structural and cultural norms mentioned by participants included professional development opportunities and stipends to purchase educational technologies and learn new techniques to implement in their courses. Ryan [GTA] described a professional development offered by his institution during the Summer 2020 semester. An

instructional designer for the college of natural science to help instructors teach more effectively online created the professional development. During his professional development Ryan learned, “how to use an educational technology, *Eco beaker* a simulation program used to interact with ecological data. Also through the summer professional development I learned how to integrate interactive simulations on D2L, and also learned how to do backwards planning. I will be using what I learned in future online classes.” Ronda [Tenured] institution also offered professional development workshops during the Fall 2020 semester through the Faculty Development Center. Faculty were incentivized with a \$500 stipend if they attended the workshops. Ronda stated, “they were really, really good at transitioning from what I did in the spring to what I did in the fall, which was very, very different. It was how to effectively engage students in an online environment and not replicate the in-person experience because you can't. Was also introduced to Top Hat, the interactive presentation software. I will use some of the techniques I learned when back face-to-face.” Participants reflected on what they learned from professional development workshops provided by their institutions and ways they will use what they learned in their current and future courses (i.e., Tophat, Ecobeaker, interactive activities online).

In summary, several factors contributed to instructors' views about teaching after the pandemic and about student learning. These factors included teacher thinking and structural and cultural norms. For example, instructors transitioned in-person lectures to synchronous video lectures and asynchronous PowerPoint lectures and uploaded them to learning management system platforms. Instructors also integrated educational technologies into their lessons, to increase student-student interaction. Instructors

believed students needed to have social interaction with peers and help each other during the learning process in a variety of different ways (i.e., D2L discussion post, Zoom breakout rooms discussions). Additionally, instructors changed the modality of their assessments, and the types of questions asked to evaluate what students learned in the course.

### **Discussion**

This study captured the teaching experiences of biology instructors teaching online during the COVID-19 pandemic and the new teaching practices they learned during this time of transition. Using components of the Teacher-Centered Systemic Reform (TCSR) Model, we sought to understand what impact, if any the pandemic had on biology instructors' teaching practices. Previous studies have shown through survey analysis that biology instructors had negative, discouraging memories of teaching during the pandemic (DeCoito & Estaiteyeh, 2022; Delgado et al., 2021; Walsh et al., 2021). In contrast, we used interview analysis to capture the teaching experiences of biology instructors teaching online during the pandemic. Our results are similar to the challenges faced by biology instructors teaching online during the pandemic. Some of the challenges participants faced were difficulty translating hands-on labs online, the speed of the transition, lack of support, lack of resources, and personal and family dynamics, which are similar to previous studies (Delgado et al., 2021; Walsh et al., 2021). However, our results also indicate positive experiences that contribute to new teaching practices, for example being more empathetic towards students, developing interactive activities online, and restructuring assessments to capture what students learned. The present study contributes to the literature on the TCSR Model, to enhance instructors teaching practices

online and TPACK understandings by providing a landscape for change in online biology instruction.

Findings from this study suggest new teaching strategies were developed during the pandemic however instructors need further training to develop these new practices to be more effective which is in line with (Driessen et al., 2020; Masiah & Primawati, 2021; Walsh et al., 2021) findings. Results also suggest personal context, structural and cultural context, and teacher thinking played a role in instructor teaching practices in the Spring 2020 semester. Of the three factors, structural and cultural context as well as teacher thinking was most prominent in the interviews. In terms of teaching strategies and curriculum implementation, results from this study indicate that teachers prioritized teaching disciplinary content facts (i.e. didactic instruction) in Spring 2020, and developed more student-centered instruction during the Fall 2020 semester. These findings suggest that in the beginning of the pandemic instructors faced difficulties integrating technology, pedagogy, and content knowledge in their online courses. However, when instructors were provided resources and professional development their instruction changed for the better by being comfortable with the online format and taking the time to develop lessons that translate well online.

The main aspect of the personal context that arose related to the instructors' family dynamics. Instructors that reflected on challenges within their families in the Spring 2020 semester (i.e. illness, taking care of small children) became more empathetic and compassionate toward their students.

Many aspects of the structural and cultural context set the tone for Spring 2020

instruction. For example, resources provided or resources lacking by the biology department or institution impacted instructors' teaching practices. Instructors that felt fully supported by their institutions had a better experience than instructors that were not supported by their institutions. The learning management systems aided instruction, however not being aware of and knowledgeable of educational technology resources constrained instruction in a variety of ways in the Spring 2020 semester. Zoom was a popular resource provided by most institutions. In Spring 2020 Zoom was used mainly as instructional technology, aiding in content delivery. After instructors had more time to use Zoom and attend professional development workshops, it was used as an educational technology by creating activities that allowed students to actively engage with the content (i.e. breakout room discussions). At the beginning of the pandemic, most instructors found it challenging to interact and communicate with students in an online setting because they could no longer read facial expressions and body language. Summer 2020 and Fall 2020 provided time for instructors and institutions to seek out resources they could align with student-centered teaching practices and help to improve student-to-teacher and student-to-student interactions.

Teacher thinking, including knowledge of content and beliefs, also had strong impact on Spring 2020 and Fall 2020 teaching practices. Instructors believed that instruction should be student-centered, but they returned to didactic instruction when teaching online at the beginning of the pandemic. In contrast, instructors' views of how students learn changed. For example, in Fall 2020 instructors integrated content-specific educational technologies in their lessons to increase student engagement with the content

(i.e. Ethogram, Ecobeaker). Instructors found it helpful for students to engage with the content using educational technologies. Others changed the way they gave exams (i.e. online quizzes) and changed the way they asked questions on exams.

There were differences in reflections between instructor types (i.e. GTA, Tenured Faculty). Prior research on biology instructors' experiences teaching online during the pandemic focused on tenured faculty only from four-year institutions (Delgado et al., 2021; Walsh et al., 2021). Our results include responses from a variety of instructor and institution types (i.e., four-year universities, two-year colleges). Instructors discussed their experiences teaching an online lab and also reflected on lecturing online. Participants' experienced many challenges trying to transfer from a hands-on in-person lab to a completely online lab. The resources and techniques instructors used (i.e., Ecobeaker, Ethogram) were different from the resources and techniques used during the lecture (i.e., Zoom, breakout rooms). These findings suggest that online labs and lectures require different techniques and resources to implement effectively online. Institutions should thoroughly think about best practices for online biology labs and lectures and create professional development workshops for all online instructors.

Beyond the COVID-19 pandemic, online teaching is a promising endeavor in a growing digital world (Biel & Brame, 2016; Davis-Berg & Kocot, 2021; DeCoito & Estaiteyeh, 2022). Therefore, biology instructors need to be equipped with the required digital literacy skills and be prepared to teach in any environment. Future research should explore professional development opportunities (i.e., faculty learning communities, collaborative workshops) to support instructors' practices through TPACK (Walsh et al.,

2021). Studies have shown the more digitally literate the instructor is, the more confident they are to integrate technology into their teaching practices (DeCoito, 2020). For example, instructors need to be prepared to teach online and be both aware of and knowledgeable of educational technologies to support their online instruction. Future research should evaluate and develop professional development for online biology instruction to spark instructional change within online education concerning effective technology integration.

### **Limitations of the Study**

Participants were recruited on a volunteer basis from a prior survey (See Chapter 3). Limitations of this study include an unequal amount of participants representing each instructor type. Of the nine participants four were Tenured Faculty from four-year institutions and one from a two-year institution, two were GTAs, one Post-Doc, and one was a Full-Time Lecturer. We should acknowledge that biology instructors may share common experiences teaching online during the pandemic, however, each instructor type also has different experiences teaching online due to the type of courses taught (i.e. lab, lecture). Because of this may be a different sampling procedure should be used for future research to get an adequate representation of each instructor type.

### **Conclusion and Implications for Future Work**

This study captured biology instructors' online teaching experiences during the COVID-19 pandemic, and what impact if any the pandemic had on their future teaching practices. Understanding the factors that contributed to new teaching practices is important when thinking of ways to further develop best teaching practices and create change for online biology instruction. Exploring educational technology integration

through a TPACK lens highlights both its effectiveness in the classroom and explores instructors' confidence with its integration. Future work must seek to explore ways to support instructors' educational technology integration and online teaching beyond an isolated event (i.e. COVID-19 Pandemic).

Considering the findings from this study more broadly and how these findings relate to the integration of educational technology and online teaching the following section provides future implications for teaching, and research.

### *Teaching*

This research is instrumental for providing an overview of challenges, strengths, and new teaching practices instructors experienced teaching online during the pandemic. It will advance knowledge about online biology teaching in higher education settings, by informing institution administrators, and online curriculum designers about the strengths and challenges associated with online teaching. Results from this study suggest biology instructors experienced many challenges transferring hands-on labs to a completely online setting. This highlights the need to reevaluate resources and support for teaching online biology labs. Studies have shown approaches to support online instruction and increase its quality (Bailey & Card, 2009; Giesber et al., 2014; Lackey, 2011), what is left out is the effectiveness of the supports (i.e. resources, peer networks). Online education should explore various ways to enhance student-student interaction and student-teacher interaction online. Also, develop authentic online assessments and promote relevant curriculum (Crawford et al., 2020).

*Research*

Future research should evaluate online education to address online teaching and educational technology integration. Future research could focus on developing professional development to support effective online teaching in biology courses. More specifically, create workshops that provide support and resources for interactive labs in an online setting (Davis-Berg & Kocot, 2021). Online observations are good to explore the effectiveness of the developed professional development programs for biology instructors. Online observations with workshop developers and peers could be beneficial to gaining an understanding of how to teach online effectively.

## References

- Allen, D., Brown, A., Karanasios, S., Norman, A. (2013). How should technology-mediated organizational change be explained? A comparison of the contributions of critical realism and activity theory. *MIS Quarterly*, 37, 835-854.
- Allen, G., Guzman-Alvarez, A., Molinaro, M., & Larsen, D. (2015). Assessing the impact and efficacy of the open-access ChemWiki textbook project. *Educause Learning Initiative Brief*. <https://net.educause.edu/ir/library/pdf/elib1501.pdf>
- Bailey, C., & Card, K. (2009). Effective pedagogical practices for online teaching: Perception of experienced instructors. *Internet and Higher Education*, 12(3).
- Biel R, Brame C. (2016). Traditional versus online biology courses: Connecting course design and student learning in an online setting. *Journal of Microbiology and Biology Education*, 17(3), 417-422. <https://doi.org/10.1128/jmbe.v17i3.1157>.
- Bennett, S., Agostinho, S., & Lockyer, L. (2017). The process of designing for learning: Understanding university teachers' design work. *Educational Technology Research and Development*, 65(1), 125–145. <https://doi.org/10.1007/s11423-016-9469-y>.
- Bernard, H. (2002). *Research methods in anthropology: Qualitative and quantitative approaches*. 3rd Alta Mira Press; Walnut Creek, CA.
- Chudler, E. H., & Bergsman, K. C. (2014). Explain the brain: websites to help scientists teach neuroscience to the general public. *CBE—Life Sciences Education*, 13(4), 577-583.
- Crawford, J., Butler-Henderson, K., Rudolph, J., Malkawi, B., Glowatz, M., Burton, R., & Lam, S. (2020). COVID-19: 20 countries' higher education intra-period digital pedagogy responses. *Journal of Applied Learning & Teaching*, 3(1), 1-20.
- Darici, D., Reissner, C., Brockhaus, J., & Missler, M. (2021). Implementation of a fully digital histology course in the anatomical teaching curriculum during COVID-19 pandemic. *Annals of Anatomy-Anatomischer Anzeiger*, 236, 151718.
- Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science*, 24(2), 97-140.
- Davis-Berg, E., & Kocot, K. (2021). Innovation in teaching and learning invertebrate zoology in remote and online classrooms. *Invertebrate Biology*, 140(1).
- DeCoito, I. (2020). The case for digital timelines in teaching and teacher education. *International Journal of e-Learning & Distance Education*, 35(1), 1-36.
- Dedoose Version **9.0.17**, web application for managing, analyzing, and presenting qualitative and mixed method research data (**2021**). Los Angeles, CA: SocioCultural Research Consultants, LLC [www.dedoose.com](http://www.dedoose.com).
- Delgado, T., Bhark, S., & Donahue, J. (2021). Pandemic teaching : Creating and teaching cell biology labs online during COVID-19. *Biochemistry and Molecular Biology Education*, 49(1), 32-37.
- Dexter, S., & Richardson, J. (2019). What does technology integration research tell us about the leadership of technology? *Journal of Research on Technology in Education*, 52(1). <https://doi.org/10.1080/15391523.2019.1668316>

- Dhawan, S. (2020). Online learning: A panacea in the time of COVID-19 crisis. *Journal of Educational Technology Systems*. <https://doi.org/10.1177/0047239520934018>
- Domagk, S., Schwartz, R. Plass, J. (2010). Interactivity in multimedia learning: An integrated model. *Computer Human Behavior*, 26(5), 1024-1033.
- Donkin, R., Askew, E., Stevenson, H. (2019). Video feedback and e-Learning enhances laboratory skills and engagement in medical laboratory science students. *BMC Medical Education*, 19(310).
- Driessen, E., Knight, J., Smith, M., & Ballen, C. (2020). Demystifying the meaning of active learning in postsecondary biology education. *CBE-Life Sciences Education*, 19(4). <https://doi.org/10.1187/cbe.20-04-0068>
- Enderle, P., Dentzau, M., Roseler, K., Southerland, S., Granger, E., & Hughers, R. (2013). Examining the influence of RET's in science teachers' beliefs and practice. *Science Education*, 98, 1077-1108.
- Englund, C., Olofsson, A., & Price, L. (2017). Teaching with technology in higher education: Understanding conceptual change and development in practice. *Higher Education Research & Development*, 36(1), 73-87. <https://doi.org/10.1080/07294360.2016.1171300>
- Fish, W., & Wickersham, L. (2009). Best practices for online instructors: Reminders. *Quarterly Review of Distance Education*, 10(3), 279-284.
- Garman, D. E., & Good, D. W. (2012). Student success: A comparison of face-to-face and online sections of community college biology courses. *Review of Higher Education & Self-Learning*, 5(16), 179-189.
- Garrett, K. (2014). A quantitative study of higher education faculty self-assessments of technological, pedagogical and content knowledge (TPACK) and technology training. (Published Dissertation). The University of Alabama, Tuscaloosa, Alabama.
- Gess-Newsome, J., Southerland, S. A., Johnston, A., & Woodbury, S. (2003). Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching. *American Educational Research Journal*, 40(3), 731-767.
- Giesbers, B., Rienties, D., Tempelaar, D., Gijsselaers, E. (2013). A dynamic analysis of the interplay between asynchronous and synchronous communication in online learning: The impact of motivation. *Journal of Computer Assisted Learning*, 30(1), 30-50. <https://doi.org/10.1111/jcal.12020>.
- Goff, E., Reindl, K., Johnson, C., McClean, P., Offerdahl, E., Schroeder, N., White, A. (2018). Investigation of a stand-alone online learning module for cellular respiration instruction. *Journal of Microbiology & Biology Education*, 19(2). <https://doi.org/10.1128/jmbe.v19i2.1460>
- Gonzalez, B. (2016). Time for action: Vision and Change implementation in an online biology course at a community college. *Journal of College Science Teaching*, 45(4), 15.
- Hodges, C., Moore, S., Lockee, B., Trust, Torrey, Bond, A. (2020, March 27). The difference between emergency remote teaching and online learning. *Educase Review*. <https://er.educause.edu/articles/2020/3/the-difference-between-emergency-remote-teaching-and-online-learning>

- Hsu, J. (2021). Promoting Academic Integrity and Student Learning in Online Biology Courses. *Journal of Microbiology & Biology Education*, 22(1), ev22i1-2291.
- Jeschofnig, L., & Jeschofnig, P., (2011). *Teaching lab science courses online: Resources for best practices, tools and technology*. San Francisco, CA. Jossey-Bass.
- Kennepohl, D., & Shaw, L. (2010). *Accessible Elements: Teaching Science Online and at a Distance*. AU Press, Canada. 283.
- Kennepohl, D. (2007). Using home-laboratory kits to teach general chemistry. *Chemistry Education Research and Practice*, 8(3). <https://doi.org/10.1039/B7RP900008B>
- Knight, J. (2007). *Instructional coaching: A partnership approach to improving instruction*. SAGE Publications.
- Kumar, N., Venugopal, D., Qiu, L., & Kumar, S. (2018). Detecting review manipulation on online platforms with hierarchical supervised learning. *Journal of Management Information Systems*, 35(1), 350-380.
- Lackey, K. (2011). Faculty development: An analysis of current and effective training strategies for preparing faculty to teach online. *Online Journal of Distance Learning Administration*, 14(5).
- Langfield, T., Colthorpe, K., & Ainscough, L. (2018). Online instructional anatomy videos: Student usage, self-efficacy, and performance in upper limb regional anatomy assessment. *Anatomical sciences education*, 11(5), 461-470.
- Lashley, M., Acevedo, M., Cotner, S., Lortie, C. (2020). How the ecology and evolution of the COVID-19 pandemic changed learning. *Ecology & Evolution*, 10(22). <https://doi.org/10.1002/ece3.6937>
- Lin, X., Gao, L. (2020). Students' sense of community and perspectives of taking synchronous and asynchronous online courses. *Asian Journal of Distance Education*, 15(1).
- Lincoln, Y., & Guba, E. (1985). *Naturalistic Inquiry*. Newbury Park, CA: Sage Publications.
- Littlefield, J. (2018). *The difference between synchronous and asynchronous distance learning*. <https://www.thoughtco.com/synchronous-distance-learning-asynchronous-distance-learning-1097959>
- Lyll, R., & Patti, A. (2010). Taking chemistry experience home: home experiemnts for kitchen chemistry. In: Kennepohl, D. Shaw L., editors. *Accessible Elements: Teaching Science Online and at a Distance*. Edmonton, Canada: AU Press, 83-108.
- Makransky, G., Borre-Gude, S., Mayer, R. (2019). Motivational and cognitive benefits of training in immersive virtual reality based on multiple assessments. *Journal of Computer Assisted Learning*, 35(6), 691-707.
- Masiah, M., & Primawati, S. (2021). Response of biology students toward online learning in the Covid-19 pandemic era. *Prisma Sains : Journal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram*, 9(1), 114.
- Maske, S. S., Kamble, P. H., Kataria, S. K., Raichandani, L., & Dhankar, R. (2018). Feasibility, effectiveness, and students' attitude toward using WhatsApp in histology teaching and learning. *Journal of Education and Health Promotion*, 7.

- Mayer, R. (2008). Applying the science of learning: Evidence based principles for the design multimedia instruction. *American Psychologist*, 63(8), 760-769. <https://doi.org/10.1037/0003-066X.63.8.760>
- McBrien, J., Rui, C., Jones, P. (2009). Virtual spaces: Employing a synchronous online classroom to facilitate student engagement in online learning. *International Review of Research in Open and Distance Learning*, 10(3). <https://doi.org/10.19173/irrodl.v.10i3.605>
- McCarthy, C. (2019). Teacher stress: balancing demands and resources. *Phi Delta Kappan*,. <https://doi.org/10.1177/0031721719885909>
- McGee, P., & Reis, A. (2012). Blended course design: A synthesis of best practices. *Journal of Asynchronous Learning Network*, 16(4). <https://doi.org/10.24059/olj.v16i4.239>
- Meigs, R. (2010). Development and pilot of the technology integration matrix questionnaire. (Published dissertation). Baker University, Bladwin City, Kansas.
- Mills, G., & Gay, L. (2016). *Education research: Competencies for analysis and applications*. London, England: Pearson Education.
- Mohammed, T. F., Nadile, E. M., Busch, C. A., Brister, D., Brownell, S. E., Claiborne, C. T., Edwards, B. A., Wolf, J. G., Lunt, C., Tran, M., Vargas, C., Walker, K. M., Warkina, T. D., Witt, M. L., Zheng, Y., & Cooper, K. M. (2021). Aspects of Large-Enrollment Online College Science Courses That Exacerbate and Alleviate Student Anxiety. *CBE life sciences education*, 20(4), ar69. <https://doi.org/10.1187/cbe.21-05-0132>
- Morse, J. (2011). Molding qualitative health research. *Qualitative Health Research*, 21(8), 1019-1021. <https://doi.org/10.1177/1049732311404706>
- Ng, W., Nicholas, H. (2013). A framework for sustainable mobile learning in schools. *British Journal of Educational Technology*, <https://doi.org/10.1111/j.1467-8535.2012.01359.x>
- Otter.ai. (2021, April). Help center: Frequently asked questions. <https://otter.ai/help-center> Pew Research Center. (2017).
- Patton, M. (2002). *Qualitative analysis and interpretation*. In: *Qualitative research and evaluation methods*. Sage Publications, Inc., Thousand Oaks.
- Paul, J., & Jefferson, F. (2019). A comparative analysis of student performance in an online vs. face-to-face environmental science course from 2009 to 2016. *Frontier Computer Science*. <https://doi.org/10.3389/fcomp.2019.00007>
- Peat, M. , & Franklin, S. (2002). Supporting student learning: The use of computer-based formative assessment modules. *British Journal of Educational Technology*, 33(5), 515-523. <https://doi.org/10.1111/1467-8535.00288>
- Procko K, Bell JK, Benore MA, et al. Moving biochemistry and molecular biology courses online in times of disruption: Recommended practices and resources - a collaboration with the faculty community and ASBMB. *Biochemistry Molecular Biology Education*, 48(5):421-427. <https://doi.org/10.1002/bmb.21354>
- Rad, F., Otaki, F., Baqain, Z., Zary, N., & Al-Halabi, M. (2021). Rapid transition to distance learning due to COVID-19: Perceptions of postgraduate dental learners and instructors. *PLOS One*, 16(6). <https://doi.org/10.1371/journal.pone.0253683>

- Rapanta, C., Botturi, L., Goodyear, P., Guardia, L., & Koole, M. (2020). Online university teaching during and after the Covid-19 Crisis: Refocusing teacher presence and learning activity. *Postdigital Science and Education*, 2, 923-945.
- Reinholz, D., Stone-Johnstone, A., Whitw, I., Sianez, L., Shah, N. (2020). A pandemic crash course: Learning to teach equitably in synchronous online classes. *CBE-Life Sciences Education*, 19(4). <https://doi.org/10.1187/cbe.20-06-0126>
- Rinaldi, C., Cavicchi, A., Spigarelli, F., Lacchè, L., & Rubens, A. (2018). Universities and smart specialization strategy: From third mission to sustainable development co-creation. *International Journal of Sustainability in Higher Education*, 19(1), 67-84. <https://doi.org/10.1108/IJSHE-04-2016-0070>
- Roddy, C., Amiet, D., Chung, J., Holt, C., Shaw, L., McKenzie, S., Garivaldis, F., Lodge, J., Mundy, M. (2017). Applying best practice online learning, teaching, and support to intensive online environments: An integrative review. *Frontier Education*, <http://doi.org/10.3389/feduc.2017.00059>
- Rupnow, R. LaDue, N. James, N., & Bergan-Roller, H. (2020). A perturbed system: How tenured faculty responded to the COVID-19 shift to remote instruction, *Journal of Chemistry Education*, 97, 2397-2407.
- Scoppio, G., & Luyt, I. (2017). Mind the gap: Enabling online faculty and instructional designers in mapping new models for quality online courses. *Education and Information Technologies*, 22(3). <https://doi.org/10.1007/s10639-015-9452-7>
- Selwyn, N., Hillman, T., Eynon, R., Ferreira, G., Knox, J. Macgilchrist, F. (2020). What's next for ed-tech? Critical hopes and concerns for the 2020s. *Learning Media and Technology*, 45(1). <https://doi.org/10.1080/17439884.2020.1694945>
- Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(1), 4-14.
- Simcock, D., Chua, W., Hekman, M., Brown, S. (2017). A survey of first-year biology student opinions regarding live lectures and recorded lectures as learning tools. *AJP Advances in Physiology Education*, 41(1), 69-76.
- Sing, V., & Thurman, A. (2019). How many ways can we define online learning? A systematic literature review of definitions of online learning (1988-2018). *American Journal of Distance Education*, 33(4).
- Spradley, J. (1979). *The ethnographic interview*. Harcourt Brace Jovanovich, San Diego.
- Supriya, K., Mead, C., Anar, A., Caulkins, J., Collins, J., Cooper, K., LePore, P., Lewis, T., Pate, A., Scott, R., Brownell, S. (2021). Undergraduate biology students received higher grades during COVID-19 but perceived negative effects on learning. *Frontier Education*, 6. <https://doi.org/10.3389/feduc.2021.759624>
- Teras, M., Suoranta, J., Teras, H., Curcher, M. (2020). Post-Covid-19 education and education technology 'solutionism': A seller's market. *Postdigital Science Education*, 2, 863-878.
- U.S. Department of Education. (2017). Use of technology in the teaching and learning.
- Varty, A. (2016). Options for online undergraduate courses in biology at American colleges and universities. *CBE-Life Sciences Education*, 15(58), 1-10.
- Walsh, L., Arango-Caro, S., Wester, E., Callis-Duehl, K. (2021). Training faculty as an institutional response to COVID-19 emergency remote teaching supported by data. *CBE-Life Sciences Education*, 20(34). 1-11.

- Wintemute, D. (2022, Apr 20). *Synchronous vs. asynchronous classes: What's the difference?* The Best Schools. <https://thebestschools.org/resources/synchronous-vs.-asynchronous-programs-courses/>
- Woodbury, S., & Gess-Newsome, J. (2002). overcoming the paradox of change without difference: a model of change in the arena of fundamental school reform. *educational policy*, 16(5), 763–782.
- Yin, R. (2017). *Case study research and applications: Design and methods (6<sup>th</sup> e.d.)*. Thousand Oaks, CA: SAGE.
- Zorfass, J. (1998). *Teaching middle school students to be active researchers*. Association for Supervision and Curriculum and Development, 1703 North Beauregard St., Alexandria, VA 22311-1714.
- Zuckerman, A., Hardesty, R., Denaro, K., Lo, S., & Owens, M. (2021). Effects of remote teaching in a crisis on equity gaps and the constructivist learning an environment in an introductory biology course series. *Journal of Microbiology and Biology Education*, 22(2).

## CHAPTER V: DISCUSSION

The growing use of educational technologies in higher education combined with an increased demand for online courses has reshaped how instructors, students, and technologies interact (Dexter & Richardson, 2019; U.S. Department of Education, 2017). Online instruction, specifically within the context of biology, may require a more significant change in instructional practice because of the abstract disciplinary content and laboratory components are typically associated with the sciences (Darling-Hammond et al., 2020). Quality online teaching requires choosing the best technological and pedagogical practices that help overcome inherent challenges in the virtual space (Darling-Hammond et al., 2020; Scoppio & Luyt, 2017).

In meeting these challenges, this work has combined the technological and pedagogical content knowledge (TPACK) Framework, with the technology integration matrix (TIM) and Teacher-Centered Systemic Reform (TCSR) model to better understand the intersection of teacher knowledge and practice related to educational technologies. Each chapter in this dissertation added to the narrative considering what factors contribute to the effective integration of educational technology to promote student learning in online biology classrooms. Specifically by looking at the intersections of disciplinary content knowledge, pedagogy knowledge, and educational technology knowledge. The following sections discuss how findings from each chapter (Chapter II, III, IV) used the TPACK Framework combined with the technology integration matrix TIM and TCSR Framework to highlight future implications for enhancing biology online instruction and effective educational technology integration.

## ***Chapter II: Systematic Literature Review***

This chapter evaluated the literature examining how higher education instructors develop their TPACK and gave a boarder perspective of how TPACK has been measured. The research questions in this section were: RQ1. How has higher education faculty TPACK been measured and assessed? RQ2. How do higher education faculty develop their TPACK? The review followed the inclusion methodology from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) group (Moher et al., 2009). The acknowledgment that educational researchers traditionally studied TPACK in generalized settings prompted several studies' suggest that future research creates qualitative and quantitative instruments in specific content areas to understand TPACK development (Benson & Ward, 2013; Nantshev et al., 2020; Ouyang & Scharber, 2018).

According to Jaikaran –Doe & Doe (2015), faculty knowledge and confidence in that knowledge are closely connected. Because teacher knowledge and confidence are closely connected (Gess-Newsome, 2015), Marcelo and Yot-Dominguez (2019) argued that it is not enough to only define faculty knowledge but to also study how educational technology is integrated into the classroom. With the specific focus on TPACK as it relates to technology integration, studies should take a closer look at discipline-based higher education faculty TPACK to better understand how to develop the needs of instructor's differing levels of technology integration (Dysart & Weckerle 2015; Koh, 2020; Rienties et al., 2013).

### **Chapter III: Instructors TPACK and Technology Integration**

Technological innovation in recent years has created a need for educational research to provide additional evidence on how learning is best supported by emerging educational technologies (Oliveira et al., 2019). This need is important in science, a discipline that shares a synergetic relationship with educational technology (Ihde, 2009; Oliveira et al., 2019). In light of this, the science discipline cannot truly be experienced without its technological dimension and thus educational technologies and science classrooms have a unique relationship in contrast to other disciplines (Jones, 2019; Oliveira et al., 2019). Therefore, it is important to explore higher education instructors' TPACK from a discipline-specific perspective to account for the specific content component of the TPACK Framework. This chapter examined biology instructors' TPACK and if it had an impact on their integration of educational technologies in their classroom teaching practices. The research questions in this section were: RQ1: How do biology instructors define educational technology? RQ2: What is the technological pedagogical content knowledge (TPACK) of biology instructors at higher education institutions? RQ2a: How does TPACK differ by instructor type? RQ3: What are biology instructors at higher education institutions' perceived technology integration levels? RQ3a: How does technology integration levels differ by instructor type? RQ4: How does TPACK influence biology instructors' technology integration?

Chapter III utilized a discipline-specific cross-sectional survey given to n=90 participants, to understand if there are any relationships between an instructor's TPACK and technology integration. In alignment with content-specific examples of technology knowledge, this study focused on biology instructors' perception of educational

technology, TPACK, and how they integrate technology in the classroom. First, findings from this study revealed instructors had higher PK, CK, and PCK but lower TCK, TPK, and TPACK, which is the same trend, shown in previous studies (Fabian et al., 2019; Jaikaran-Doe & Doe, P., 2015; Morales et al., 2019; Scott & Nimon, 2020). In line with Castañeda & Selwyn (2018) the most common learning environment was active learning, which supports the importance of student engagement when integrating technology. TPACK scores and technology integration levels did not have a direct relationship, but there were groups of instructors that had similar TPACK and technology integration. Related literature suggests biology teachers' TPACK relates to the technology integration and pedagogy in teaching (Nasution et al., 2017). While those findings provide an insight into biology teachers' technology integration and pedagogy using educational technologies, they leave out variables that may influence technology integration. This further supports exploring factors that influence biology instructors' educational technology integration in the classroom.

#### **Chapter IV: Approaches to Teaching During Covid-19**

Online instruction offers a different way for instructors and students to interact and create learning environments that remove barriers, for example, location, and travel (Dhawan, 2020; McBrien et al., 2009). However, the removed barriers are only valuable if courses are effectively facilitated (Beil & Brame, 2016). The experiences of the COVID-19 pandemic have created questions for instructors, students, and policymakers, in regard to curriculum, and effective online teaching practices (Hodges et al., 2020; Rapanta et al., 2020). Given the magnitude of students who are currently engaging in online courses and the likelihood of online courses becoming more common among

institutions of higher education it is important to understand the landscape of online biology course offerings and the instructors that teach those courses (Mohammed et al., 2021). From this perspective, it is important to examine technology integration and online teaching through a TPACK lens to understand what factors contribute to their teaching practices.

This chapter examined biology instructors' experiences teaching online during the COVID-19, and if it influenced their current teaching practices. The research questions in this section were: RQ1: What were Biology instructors' experiences teaching online during the COVID-19 pandemic? RQ2: What teaching practices did biology instructors sustain after their initial online experience? To answer the above research questions semi-structured interviews were conducted with n=9 participants. This study revealed similar challenges (i.e. speed of transition, lack of resources, lack of support) faced by biology instructors teaching online during the pandemic from previous studies (Delgado et al., 2021; Walsh et al., 2021). However, findings also indicate positive experiences that contribute to new teaching practices. For example, biology instructors developed interactive activities online and restructured assessments. These findings hold practical implications for how instructors can equip themselves with best teaching practices online to enhance student learning. Implications include increased training and resources to support online instruction and increase its quality.

### **Conclusion**

This dissertation contributes to a wider body of research that seeks to understand how TPACK and other factors impact effective online teaching and technology integration. Factors that contribute to effective online teaching and technology integration

are complex, meaning there is not just one factor that contributes to the effectiveness.

There is a complex interaction between TPACK (teacher knowledge) and online teaching practice (what they do in the classroom) and what students are learning in the process.

Further research can play an important role in exploring the complexities of TPACK and enhance the effectiveness of online instruction through professional development.

### References

- Biel R, Brame C. (2016). Traditional versus online biology courses: Connecting course design and student learning in an online setting. *Journal of Microbiology and Biology Education*, 17(3), 417-422. <https://doi.org/10.1128/jmbe.v17i3.1157>.
- Benson, S., & Ward, C. (2013). Teaching with technology: Using TPACK to understand teaching expertise in online higher education. *Journal of Education Computing Research*, 48(2), 153-172.
- Castañeda, L., Selwyn, N. (2018). More than tools? Making sense of the ongoing digitizations of higher education. *International Journal of Educational Technology in Higher Education*, 15, 22 <https://doi.org/10.1186/s41239-018-0109-y>.
- Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science*, 24(2), 97-140.
- Delgado, T., Bhark, S., & Donahue, J. (2021). Pandemic teaching : Creating and teaching cell biology labs online during COVID-19. *Biochemistry and Molecular Biology Education*, 49(1), 32-37.
- Dexter, S., & Richardson, J. (2019). What does technology integration research tell us about the leadership of technology? *Journal of Research on Technology in Education*, 52(1). <https://doi.org/10.1080/15391523.2019.1668316>
- Dhawan, S. (2020). Online learning: A panacea in the time of COVID-19 crisis. *Journal of Educational Technology Systems*. <https://doi.org/10.1177/0047239520934018>
- Dysart, S., & Weckerle, C. (2015). Professional development in higher education: A model for meaningful technology integration. *Journal of Information Technology Education: Innovations in Practice*, (14), 255-265.
- Fabian, K., Clayes, E., & Kelly, L. (2019). Putting design into practice: An investigation of TPACK scores of lecturers in a networked institution. *Research in Learning Technology*, 27.
- Gess-Newsome, J. (2015). Re-examining pedagogical content knowledge in science education (A. Berry, P. Friedrichsen, & J. Loughran, Eds.) Routledge.
- Hodges, C., Moore, S., Lockee, B., Trust, Torrey, Bond, A. (2020, March 27). The difference between emergency remote teaching and online learning. *Educase Review*. <https://er.educause.edu/articles/2020/3/the-difference-between-emergency-remote-teaching-and-online-learning>
- Ihde, D. (2009). Postphenomenology and technoscience: The Peking university lectures. Albany, NY: State University of New York Press.
- Jaikaran-Doe, S., & Doe, P. (2015). Assessing technological pedagogical content knowledge of engineering academics in an Australian regional university. *Australia Asian Journal of Engineering Education*, 20(2), 157-167. <https://doi.org/10.1080/22054952.2015.1133515>
- Koh, J. (2020). Three approaches for supporting faculty technological pedagogical content knowledge (TPACK) creation through instructional consultation. *British Journal of Educational Technology*, 51(6), 2529-2543. <https://doi.org/10.1111/bjet.12930>

- Marcelo, C., & Yot-Domínguez, C. (2019) From chalk to keyboard in higher education classrooms: Changes and coherence when integrating technological knowledge into pedagogical content knowledge, *Journal of Further and Higher Education*, 43(7), 975-988. <https://doi.org/10.1080/0309877X.2018.1429584>.
- McBrien, J., Rui, C., Jones, P. (2009). Virtual spaces: Employing a synchronous online classroom to facilitate student engagement in online learning. *International Review of Research in Open and Distance Learning*, 10(3). <https://doi.org/10.19173/irrodl.v.10i3.605>
- Mohammed, T. F., Nadile, E. M., Busch, C. A., Brister, D., Brownell, S. E., Claiborne, C. T., Edwards, B. A., Wolf, J. G., Lunt, C., Tran, M., Vargas, C., Walker, K. M., Warkina, T. D., Witt, M. L., Zheng, Y., & Cooper, K. M. (2021). Aspects of Large-Enrollment Online College Science Courses That Exacerbate and Alleviate Student Anxiety. *CBE life sciences education*, 20(4), ar69. <https://doi.org/10.1187/cbe.21-05-0132>
- Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009 Jul 21;6 (7). <https://doi.10.1371/journal.pmed.1000097>. Epub. 2009. Jul 21. PMID: 19621072.
- Morales, M., Anito, J., Avilla, R., Abulon, E., & Palisoc, C. (2019). Proficiency indicators for Philippine STEAM (science, technology, engineering, agri/fisheries, mathematics) educators. *Philippine Journal of Science*, 148(2), 263-275.
- Nantshev, R., Feuerstein, E., González, R., Alonso, I., Hackl, W., Petridis, K., Triantafyllou, E., & Ammenwerth, E. (2020). Teaching approaches and educational technologies in teaching mathematics in higher education. *Education Sciences*, 10(354). <https://doi.org/10.3390/educsci10120354>
- Nasution, W., Sriyati, S., Riandi, R., Safitri, M. (2017). Mastery of content representation (CoRes) related TPACK high school biology teacher. *Journal of Physics Conference Series*, 895(1). <https://doi.org/10.1088/1742-6596/895/1/012135>
- Oliveira, A., Feyzi Behnagh, R., Burgess, K., Guo, L. (2019). Emerging technologies as pedagogical tools for teaching and learning science: A literature review, *Uses of Emerging Technologies, Special Issue Article*, <https://doi.org/10.1002/hbe2.141>
- Ouyang, F., & Scharber, C. (2018). Adapting the tpack framework for online teaching within higher education. *International Journal of Online Pedagogy and Course Design*, 8(1).
- Rapanta, C., Botturi, L., Goodyear, P., Guardia, L., & Koole, M. (2020). Online university teaching during and after the Covid-19 Crisis: Refocusing teacher presence and learning activity. *Postdigital Science and Education*, 2, 923-945.
- Rienties, B., Brouwer, N., Carbonell, K., Townsend, D., Rozendal, A., van der Loo, J., Dekker, P., & Lygo-Baker, S. (2013). Online training of TPACK skills of higher education scholars: a cross-institutional impact study. *European Journal of Teacher Education*, 36(4), 480-495. <https://dx.doi.org/10.1080/02619768.2013.801073>

- Scoppio, G., & Luyt, I. (2017). Mind the gap: Enabling online faculty and instructional designers in mapping new models for quality online courses. *Education and Information Technologies*, 22(3). <https://doi.org/10.1007/s10639-015-9452-7>
- Scott, K., & Nimon, K. (2020). Construct validity of data from a tpack self-assessment instrument in 2-year public college faculty in the United States, *Journal of Research on Technology in Education*. <https://doi.org/10.1080/15391523.2020.1790444>
- Walsh, L., Arango-Caro, S., Wester, E., Callis-Duehl, K. (2021). Training faculty as an institutional response to COVID-19 emergency remote teaching supported by data. *CBE-Life Sciences Education*, 20(34). 1-11.
- U.S. Department of Education. (2017). Use of technology in the teaching and learning.

## APPENDIX A: Overview of Studies Included in Systematic Review

Authors	Study Design	Interview	Surveys	Observation /Content Analysis	Redesign Model	Focus Tech	TPACK Course	Development of TPACK (subject specific)
Amhage et al. (2019)	Mixed Methods		X					
Benson & Ward (2013)	Case Study	X		X				
Brinkley-Etz Korn (2018)	Mixed Methods		X	X	X		X	
Chukuemeka & Iscioglu (2016)	Quantitative		X					
Cubeles & Riu (2018)	Descriptive quantitative		X					Engineering, Architecture & Business
Dysart & Weckerle (2015)	Design-Based Research				X			
Espinoza & Neal (2018)	Theoretical Study				X			
Fabian et al. (2019)	Quantitative		X					
Faizan et al. (2019)	Empirical Study		X					
Fernandes & Gupta (2019)	Quasi-Experiment			X				
Foulger et al. (2015)	Case Study	X					X	
Jaikaran-Doe & Doe (2015)	Quantitative		X					Engineering
Koh (2020)	Action Research					X		
Marcelo & Yot-Dominquez (2019)	Quasi-Experiment	X	X					
Morales et al. (2019)	Design-Based		X					STEAM (Science,

	Research							Technology, Engineering, Agriculture, Mathematics
Nantshev et al. (2020)	Mixed Methods	X	X					Mathematics
Oyung (2018)	Case Study			X				
Rienties et al. (2013)	Mixed Methods		X		X			
Scott & Nimon (2020)	Quantitative		X					
Sjöberg & Lilja (2019)	Mixed Methods	X	X					
Soomro et al. (2018)	Mixed Methods	X	X					
Wu et al. (2016)	Mixed Methods			X	X	X		

APPENDIX B: Modified HE-TPACK Survey

# HE-TPACK Survey

---

Start of Block: Block 2

Please indicate your consent and eligibility by answering the following questions. [Link](#)

Click to write Column 1

Yes (1)

No (2)

I have read the informed consent document pertaining to the research. (1)

The research procedures are clear to me. (2)

I confirm I am 18 years old or older (3)

I am aware of the potential risks of the study (4)

---

Please indicate your consent below. By clicking below, I affirm that I freely and voluntarily choose to participate in this study. I understand I can withdraw from this study at any time.

No, I do not consent (2)

Yes, I consent (3)

*Skip To: End of Survey If Please indicate your consent below. By clicking below, I affirm that I freely and voluntarily cho... = No, I do not consent*

**End of Block: Block 2**

---

**Start of Block: Default Question Block**

3 Which of the following best describes your current position?

Graduate Teaching Assistant (1)

Adjunct Instructor (2)

Faculty Tenure-Track (3)

Faculty Non-Tenure Track (4)

Post-Doc (6)

Other (5) \_\_\_\_\_

---

4 Which of the following best describes your current institution?

Four Year University (1)

Community College (2)

Other (3) \_\_\_\_\_

-----

4 Number of years teaching experience as a higher education biology instructor?

0 year (1)

1-3 years (2)

4-7 (3)

8-11 (4)

12-15 (5)

16+ (6)

-----

Page Break \_\_\_\_\_

5 What course(s) did you teach Fall 2020?

General Biology (majors) (1)

Introductory Biology (non-majors) (2)

Human Anatomy (3)

Other (11) \_\_\_\_\_

---

Q32 How were these courses taught? (Select all that apply)

asynchronous (self-paced online course with deadlines) (1)

synchronous (live video classroom) (2)

Hybrid (in-person and online) (3)

Other (4) \_\_\_\_\_

---

7 What course(s) did you teach Spring 2021 ?

General Biology (Majors) (1)

Introductory Biology (Non-majors) (2)

Human Anatomy (3)

Other (10) \_\_\_\_\_

---

8 How were these courses taught? (Select all that apply)

asynchronous (self-paced online course with deadlines) (1)

synchronous (live video classroom) (2)

Hybrid (in-person and online) (3)

Other (4) \_\_\_\_\_

---

Page Break \_\_\_\_\_

	Strongly Disagree (1)	Disagree (2)	Not Sure (3)	Agree (4)	Strongly Agree (5)
I have a clear understanding of pedagogy within the course I teach (e.g., designing instruction, assessing students' learning). (5)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am familiar with a variety of hardware, software, and technology tools that I can use for teaching (6)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I have a comprehensive understanding of the curriculum I teach (7)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I understand that there is a relationship between content and the teaching methods used to teach biology (8)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I understand how teaching and learning change when certain educational technologies are	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

used. (9)

I understand how the choice of technologies allows and limits the types of content ideas that can be taught (10)

I integrate educational technologies to increase student opportunities for interaction with ideas. (11)

I am familiar with a wide range of practices, strategies, and methods that I use in my teaching (12)

I know how to troubleshoot technology problems when they arise. (13)

I explain to students the value of knowing concepts in biology. (14)

I recognize that educational technology use can have positive and negative effects.

(15)

I stay abreast of new research related to my discipline in order to keep my own understanding of biology updated. (16)

I can provide multiple representations of biology content in the form of analogies, examples, demonstrations, and classroom activities. (17)

I am aware of how different technologies can be used to provide multiple and varied representations of the same biology content. (18)

I understand that I need to be flexible when using technology for instructional purposes. (19)

10  
Thi  
nk  
abo  
ut  
the  
cou  
rse  
you  
tau  
ght  
in  
Fall  
202  
0  
and  
Spr  
ing  
202  
1.  
Usi  
ng  
the  
foll  
owi  
ng  
scal  
e,  
to  
wh  
at  
ext  
ent  
do  
you  
agre  
e  
wit  
h  
the

statements below?(1-Strongly Disagree, 2-Disagree, 3-Not Sure, 4-Agree, 5- Strongly Agree )

11 Think about the courses you taught in Fall 2020 and Spring 2021. Using the following scale, to what extent do you agree with the statements below?

(1-Strongly Disagree, 2-Disagree, 3-Not Sure, 4-Agree, 5- Strongly Agree )

	Strongly Disagree (1)	Disagree (2)	Not Sure (3)	Agree (4)	Strongly Agree (5)
I can anticipate and address students' preconceptions and misconceptions. (1)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I understand how educational technology can be integrated into teaching and learning to help students achieve specific pedagogical goals. (2)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I motivate my students to use educational technologies to support their individual learning. (3)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I know how to assess student learning (4)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I can decide when educational technology can be beneficial to achieving student learning . (5)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

I make connections between the different topics in biology. (6)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I understand what biology topics or concepts are easy or difficult to learn. (7)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I know how to be flexible with my use of educational technology to support teaching and learning. (8)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I understand what makes certain concepts difficult to learn for students and how technology can be used to leverage that knowledge to improve student learning gains. (9)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I know how to motivate students to learn. (10)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I understand how to integrate educational technology to build upon	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

students' prior  
knowledge of  
biology  
content. (11)

I know how to  
operate  
educational  
technologies  
and can  
incorporate  
them into  
biology courses  
to enhance  
student  
learning. (12)



---

9 How would you define educational technology?

---

---

---

---

---

12 What educational technologies have you used in the past year? Select all that apply.

Augmented Reality (1)

Computer Simulation (2)

Virtual Lab (3)

Animations (4)

Clickers (5)

Mobile Learning App (7)

Other (8) \_\_\_\_\_

-----

13 Think about the courses you taught in Spring 2021. Which of the following best describes your classroom environment when integrating one of the educational technologies listed above?

- Students are engaged in using educational technology as a tool rather than passively receiving information from the technology. (1)
- Students use educational technology to collaborate with others rather than working individually at all times. (2)
- Students use educational technology to connect new information to their prior knowledge rather than to passively receive information. (3)
- Students use educational technology to link learning activities to the world beyond the instructional setting rather than working on decontextualized assignments. (4)
- Students use educational technology to set goals, plan activities, monitor progress, and evaluate results rather than simply completing assignments without reflection. (5)

---

*Display This Question:*

*If Think about the courses you taught in Spring 2021. Which of the following best describes your cla... = Students are engaged in using educational technology as a tool rather than passively receiving information from the technology.*

14 In your classroom which scenario is most likely to be accurate?

The instructor may be the only one actively using educational technology. This may include using presentation software to support delivery of a lecture. The instructor may also have the students' complete practice activities on mobile devices.

(1)

The instructor guides the type of educational technology used. The instructor may be pacing the students through a project, making sure that they each complete every step in the same sequence with the same educational technology. (2)

The instructor allows for some student choice and exploration of the educational technology. The instructor acts as a facilitator toward learning, allowing student engagement with educational technology. (3)

The instructor guides, informs, and contextualizes student choices of educational technology and is flexible and open to student ideas. Lessons are structured so that student use of educational technology is self-directed. (4)

The instructor serves as a guide the use of educational technology. The instructor encourages and supports the active engagement of students with educational technology resources. Instructor facilitates lessons in which students are engaged in higher-order learning activities that may not have been possible without the use of educational. (5)

---

14b In your classroom which scenario is most likely to be accurate?

- The instructor directs students to work alone on tasks involving education technology. Students primarily work alone when using educational technology. Students may collaborate without using educational technology. (1)
- The instructor directs students in the conventional use of educational technology tools for working with others. These opportunities for collaboration with others through educational technology, are limited and are not a regular part of their learning. (2)
- The instructor provides opportunities for students to use educational technology to work with others. Students independently use educational technology tools in conventional ways for collaboration. (3)
- The instructor fosters a collaborative learning environment and supports students meaningful choices in their selection of educational technology tools for collaboration. Educational technology use for collaboration by students is regular and normal in this setting. Students choose the best educational technology to use to accomplish their work. (4)
- The instructor seeks partnerships outside of the setting to allow students to access experts and peers in other locations, and encourages students to extend the use of

collaborative educational technology tools in higher-order learning activities that may not be possible without the use of the technology. (5)

*knowledge rather than to passively receive information.*

14c In your classroom which scenario is most likely to be accurate?

- The instructor uses educational technology to deliver information to students. Students receive information from the instructor via technology. (1)
- The instructor provides some opportunities for students to use educational technology in conventional ways to build knowledge and experience. The students construct meaning about the relationships between prior knowledge and new learning, but the instructor makes the choices regarding educational technology use. (2)
- The instructor creates an environment in which students use educational technology to build an understanding of a biology concept. The instructor give students access to educational technology and guide them in exploring and choosing appropriate resources. Students begin to use educational technology independently to facilitate construction of meaning. (3)
- The instructor consistently allows students to select educational technology tools to use in building an understanding of a biology concept. Students consistently have opportunities to select educational technology and use them in the way that best facilitates their construction of understanding biology concepts. (4)
- The instructor facilitates higher-order learning opportunities in which students regularly engage in activities that may be difficult to achieve without the use of educational technology. Students gain a deeper understanding of the educational

technology and allows them to extend the use of the tools in creative ways to construct meaning. (5)

---

*Display This Question:*

*If Think about the courses you taught in Spring 2021. Which of the following best describes your cla... = Students use educational technology to link learning activities to the world beyond the instructional setting rather than working on decontextualized assignments.*

14d In your classroom which scenario is most likely to be accurate?

- The instructor assigns work based on a predetermined curriculum. Students use educational technology to complete assigned activities that are generally unrelated to the world beyond the instructional setting. (1)
- The instructor directs students in the conventional use educational technology tools for learning activities that are sometimes related to the students or to issues beyond the instructional setting. Students have opportunities to apply educational technology to some content-specific activities that are related to the students or issues beyond the instructional setting. (2)
- The instructor creates purposefully lessons that integrate educational technology and provide access to information on community and world issues. The instructor directs the choice of educational technology but students use the tools on their own, and may begin to explore other capabilities of the tools. (3)
- The instructor encourages students to use educational technology to make connections to the world outside of the instructional setting, and to their lives and

interests. The instructor provides a learning context in which students regularly use educational technology and have the freedom to choose the tools that, for each student, best match the task. (4)

The instructor encourages innovative use of technology tools in higher-order learning activities that support connections to the lives of the students and the world beyond the instructional setting. Students explore and extend the use of educational technology to participate in higher-order learning activities that have meaning in the world beyond the instructional setting. (5)

---

*Display This Question:*

*If Think about the courses you taught in Spring 2021. Which of the following best describes your cla... = Students use educational technology to set goals, plan activities, monitor progress, and evaluate results rather than simply completing assignments without reflection.*

14e In your classroom which scenario is most likely to be accurate?

- The instructor gives students directions and monitors step-by-step completion of tasks. The instructor sets goals for students and monitors their progress. Students may receive directions, guidance, and/or feedback via educational technology. (1)
  
- The instructor directs students step by step in the conventional use of educational technology to set goals, plan, monitor, evaluate an activity, or reflect upon learning activities. Students following instructions to use educational technology to set goals, plan, monitor, evaluate, or reflect upon an activity. (2)
  
- The instructor selects the educational technology and clearly integrate them into the lesson. The instructor facilitates students' independent use of the educational technology to set goals, plan, monitor progress, evaluate outcomes, and reflect upon learning activities. Instructor provide guidance in breaking down tasks. (3)
  
- The instructor creates a learning context in which students regularly use educational technology to set goals, plan, monitor, evaluate outcomes, and reflect upon learning activities. Instructor facilitates students' choice and independent use of educational technology to accomplish these tasks. (4)
  
- The instructor creates a rich learning environment in which students regularly engage in higher-order planning, monitoring, evaluative, and reflective activities that may be impossible to achieve without educational technology. The instructor sets a

context in which students are encouraged to use technology tools in innovative ways to direct and reflect on their own learning. (5)

---

Page Break

1 Ethnicity: How do you identify? (Select all that Apply)

White (1)

Black or African American (2)

Hispanic (3)

Asian (4)

Native Hawaiian or Pacific Islander (5)

Middle Eastern (6)

Other (7) \_\_\_\_\_

-----

2 Gender: How do you identify?

- Male (1)
  - Non-binary (2)
  - Female (3)
  - Prefer not to answer (4)
  - Prefer to self describe below (5)
- 

19 Would like to do a follow-up interview? (Optional)

- Yes (1)
- No (2)

*Skip To: 18 If Would like to do a follow-up interview? (Optional) = Yes*

---

18 Would you like to be considered for an Amazon Gift Card (Optional)

- Yes (6)
- No (7)

**End of Block: Default Question Block**

## APPENDIX C: Technology Integration Evaluation Scores &amp; Criteria

<b>Learning Environment</b>	<b>Likert Score</b>	<b>Technology Integration Level</b>	<b>Likert Score</b>	<b>Environment + Technology Integration Level</b>	<b>High Moderate Low</b>
Active learning	1	Entry Level	1	Active Entry 2	Low
		Adoption Level	2	Active Adoption 3	Low
		Adaptation Level	3	Active Adaptation 4	Low
		Infusion Level	4	Active Infusion 5	Low
		Transformation Level	5	Active Transformation 6	Low
Collaborative Learning	2	Entry Level	6	Collaborative Entry 8	Low
		Adoption Level	7	Collaborative Adoption 9	Low
		Adaptation Level	8	Collaborative Adaptation 10	Low
		Infusion Level	9	Collaborative Infusion 11	Low
		Transformation Level	10	Collaborative Transformation 12	Low
Constructive Learning	3	Entry Level	11	Constructive Entry 14	Moderate
		Adoption Level	12	Constructive Adoption	Moderate

				15	
		Adaptation Level	13	Constructive Adaptation 16	Moderate
		Infusion Level	14	Constructive Infusion 17	Moderate
		Transformation Level	15	Constructive Transformation 18	Moderate
Authentic Learning	4	Entry Level	16	Authentic Entry 20	Moderate
		Adoption Level	17	Authentic Adoption 21	Moderate
		Adaptation Level	18	Authentic Adaptation 22	Moderate
		Infusion Level	19	Authentic Infusion 23	Moderate
		Transformation Level	20	Authentic Transformation 24	Moderate
Goal-Directed Learning	5	Entry Level	21	Goal-Directed Learning Entry 26	High
		Adoption Level	22	Goal-Directed Learning Adoption 27	High
		Adaptation Level	23	Goal-Directed Learning Adaptation 28	High
		Infusion Level	24	Goal-Directed Learning Infusion 29	High

## APPENDIX D: Interview Protocol

**Demographic/General**

1. What is your current position at your institution?
2. How many years of teaching experience do you have?
3. Prior to the Covid-19 pandemic did you teach online? If yes, were these courses asynchronous (self-paced online courses with deadlines) synchronous (video classroom) or hybrid (self-paced online with deadlines) synchronous or asynchronous?
3. What courses did you teach during the pandemic?
4. Were these courses asynchronous (self-paced online courses with deadlines) synchronous (video classroom) or hybrid (self-paced online with deadlines and some face-to-face)?
5. What courses do you currently teach? Are these courses asynchronous (self-paced online courses with deadlines) synchronous (video classroom) or hybrid (self-paced online with deadlines and some face-to-face)?

**Reflecting on Rapid Transition to Online Teaching**

6. How did you perceive the pivot to online instruction due to the pandemic?
7. What types of resources did you seek out when preparing to shift instruction?
8. What types of technology resources did your institution provide for online instruction?
9. What instructional practices and course activities did you use in your online courses? Additionally, were some practices more effective than others?
10. Are there any classroom activities you once viewed as necessary that you now view as less important or vice versa? What are they? Why?

**New Teaching Practices**

11. How did you plan to approach Spring 2021? (Did you plan for online instruction, face-to-face instruction, or hybrid instruction?)
12. What did you learn from Fall 2020 (i.e. teaching strategy, revised course syllabus, revised assessment) that you will use in your classroom moving forward?

**Reflecting on Impact**

13. What long-term effects did Spring 2020 have on your view of teaching online?
14. What long-term effects did Spring 2020 have on your view of educational technology? Why?
15. Tell me about your experience teaching online.
16. What, if any, impact has online instruction had on your view of yourself as a teacher?

APPENDIX E: *A priori Codebook (Rupnow et al., 2020)***Table 1. Teaching Practices Codes and Description**

Focus Code	Definition	Examples
Continuing instructional practice	Face-to-face practices employed previously and retained in the online environment	PowerPoint, lecture, online materials, online homework
New Instructional Practice	New practice employed for online environment	Creating new problems, incorporating animations
Discontinued instructional practice	Face-to-face practices employed previously but not retained after transition to remote environment	Using chalkboard, body language, active learning
Future Instructional Practice	Practices to be retained in the future, new practices to be adopted, future improvement to teaching	Start asking students to use cameras, expect return to normal in the fall, accelerating online teaching trends.

**Table 2. Personal Context Codes and Descriptions**

Focus Code	Definition	Examples
Teaching experience	Describing experience in the classroom	Having taught the course a long-time, experience with blackboard
Career stage	Views about teaching online related to career stage, investment in teaching related to career stage	Nearing retirement, not teaching this online again

**Table 3. Structural and Cultural Context Codes and Descriptions**

Focus Code	Definition	Examples
Institutionalized platforms	Technology has been selected and provided by the institution or department that is a resource for faculty or students	LMS, Blackboard Ultra/Collaborate, Microsoft Teams, McGraw Hill Connect
Institutionally provided professional development	Training available through official organizations, discussion forums, and website curated/ run by university	Special seminars, Keep Teaching website, faculty development office
People in institution	Individual contacts on campus able to assist in thinking through and/ or approaching instruction	Friends, faculty, IT people
Resources lacking	Physical tools, technological tools, or knowledge, desired but unavailable to instructor or student	Proctoring services, other meeting platforms, tablet/stylus, students or professor availability
Outside resources	Solicited or unsolicited advertised resources, technology, curricular	Email advertisements sent by publishers

	materials	
Modes of communication	Modalities the students and faculty can communicate or interact existing in any teaching context (online or face-to-face)	Communicating by chat, raising hand, moving around room
Expectations/cultural norms	Assertions about how the department/institution functions with respect to teaching and learning	Belief that institution requires platform, adherence to the syllabus, communicating with colleagues about instruction

**Table 4. Teacher Thinking Codes and Descriptions**

Focus Code	Definition	Examples
Pedagogical inclinations	Purpose of instruction, value of various pedagogies (how to teach, what tools to use)	Best way to teach, best tools for content delivery
Impact of online environment	Perceptions of online learning as inferior, difficult, unpleasant, or superior to face-to-face learning	More effective in person, need for full sensory experience (smell, sound, touch)
Empathy for students	Concern or lack of concern for student needs, preferences, challenges, or negative views of students	Students are trying, students have technology limitations, students are taking advantage of circumstance
Student-faculty-communication	Importance/value of communication, feedback between student and faculty	Audio visual cues, body language, discussion
Purpose of assessment	A belief about the purposed or nature of assessment	Process is more important than answer, the point of homework is to learn, the purpose of assessment is to rank students
Academic dishonesty	Belief or perception (by instructor or students) the students are cheating	Answers available online, belief that students are using online resources during exams