2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33925

Computational Thinking in the Formation of Engineers (Year 1)

Dr. Noemi V. Mendoza Diaz, Texas A&M University

Dr. Mendoza Diaz is Assistant Professor at the College of Education and Human Development with a courtesy appointment in the College of Engineering at Texas A&M University. She obtained her Ph.D. from Texas A&M University in Educational Administration and Human Resource Development and worked as a Postdoctoral Researcher with the Institute for P-12 Engineering Research and Learning-INSPIRE at the School of Engineering Education-Purdue University. She was a recipient of the Apprentice Faculty Grant from the Educational Research Methods ASEE Division in 2009. She also has been an Electrical Engineering Professor for two Mexican universities. Dr. Mendoza is interested in sTEm education, socioeconomically disadvantaged students, Latino studies in engineering and computer aided/instructional technology in sTEm.

Dr. Russ Meier, Milwaukee School of Engineering

Dr. Russ Meier is a Professor of Electrical Engineering and Computer Science at the Milwaukee School of Engineering. He received his B.S., M.S., and Ph.D. degrees in Computer Engineering from Iowa State University. His teaching and research interests include embedded systems, evolvable hardware, the use of complex adaptive systems in digital architectures, and computer architecture. He has a 25 year history of teaching excellence at the undergraduate and graduate levels. His teaching skills have been recognized with an Iowa State University Teaching Excellence Award, the Iowa State University Warren B. Boast Award for Undergraduate Teaching Excellence, and the MSOE Oscar Werwath Distinguished Teacher Award.

Dr. Meier maintains professional memberships in the American Society for Engineering Education (ASEE), the ASEE Electrical and Computer Engineering Division (ECE), the ASEE Educational Research and Methods division (ERM),the Institute for Electrical and Electronics Engineers (IEEE), the IEEE Computer Society, and the IEEE Education Society.

Dr. Meier serves the engineering education community in a number of ways through leadership roles in his professional societies as well as work within ABET accreditation activities. He has held multiple officer positions within ASEE and IEEE and has worked with worldwide teams to release products and services to enhance the professional life of engineering and computer science educators. In 2012, the International Society for Engineering Education awarded Dr. Meier the title International Engineering Educator Honoris Causa for outstanding contributions in the field of Engineering Education and for dedicated work as an engineering educator. In 2018, the IEEE bestowed the Fellow grade upon Meier for outstanding contributions to global online engineering education.

Dr. Deborah A. Trytten, University of Oklahoma

Dr. Deborah A. Trytten is an Associate Professor of Computer Science and Womens' and Gender Studies at the University of Oklahoma. Her main research focus is diversity in engineering education and introductory software engineering education.

Dr. So Yoon Yoon, University of Cincinnati

So Yoon Yoon, Ph.D., is a research scientist at the Department of Engineering Education in the College of Engineering and Applied Science (CEAS) at the University of Cincinnati. She received her Ph.D. in Gifted Education, and an M.S.Ed. in Research Methods and Measurement with a specialization in Educational Psychology, both from Purdue University. Her work centers on engineering education research as a psychometrician, program evaluator, and data analyst, with research interests in spatial ability, creativity, engineering-integrated STEM education, and meta-analysis. As a psychometrician, she has revised, developed, and validated more than 10 instruments beneficial for STEM education practice and research. She has authored/co-authored more than 50 peer-reviewed journal articles and conference proceedings and served as a journal reviewer in engineering education, STEM education, and educational psychology. She has also served as a co-PI, an external evaluator, or an advisory board member on several NSF-funded projects.

Dr. Janie M. Moore, Texas A&M University

Dr. Janie McClurkin Moore is an Assistant Professor in the Biological and Agricultural Engineering Department at Texas A&M University in College Station. A native of Columbus, Ohio, she attended North Carolina A&T State University where she received a B.S. in Bio Environmental Engineering in 2006. She then began pursuing her graduate education at Purdue University in the Agricultural and Biological Engineering Department, completing her Ph.D. in 2015. Her primary research areas include 1) mycotoxin risk assessment and treatment in stored grains and 2) innovate instructional strategies for Biological and Agricultural Engineering students.

Dr. Andrea M. Ogilvie P.E., Texas A&M University

Andrea M. Ogilvie, Ph.D., P.E. serves as Assistant Dean for Student Success and Assistant Professor of Instruction in the College of Engineering at Texas A&M University. She is an engineering education researcher and practitioner who draws on decades of experience in engineering and higher education. Since 2014, Dr. Ogilvie's research has focused on engineering transfer students and their experiences at both sending and receiving institutions. More broadly, her research interests center on higher education policy issues, workforce development, and broadening participation in STEM. Dr. Ogilvie holds multiple degrees in engineering and public affairs from UT Austin (BS Civil Engineering, Master of Public Affairs) and Virginia Tech (MS Industrial and Systems Engineering, PhD Engineering Education).

Dr. Mark Weichold, Texas A&M University

Dr. Mark H. Weichold, Regents Professor and Halliburton Engineering Global Programs Professor, is an electrical engineer and has worked for General Dynamics Ft. Worth Division, Motorola in Austin, TX and the U.S. Army Electronic Technology and Devices Laboratory in Ft. Monmouth, NJ. He joined the Electrical Engineering faculty at Texas A&M University in 1982 and now holds the rank of Professor.

In January 2007, he became Dean and CEO of Texas A&M University's branch campus in Doha, Qatar. After completing nine years as the Dean and CEO of Texas A&M at Qatar, he returned to College Station to assume the role of Senior Associate Dean in the College of Engineering.

He is a Life Fellow of the IEEE, a member of the American Physical Society, an ABET program evaluator, and a licensed professional engineer in the State of Texas. In 2013, he was awarded the Abdullah bin Hamad Al Attiyah International Energy Award for 'Lifetime Achievement for the Advancement of Education'.

Computational Thinking Diagnostics for First-Year Engineering Students: Year I

Computational thinking is understood as the development of skills and knowledge in how to apply computers and technology to systematically solve problems. Computational thinking has been acknowledged as one key aspect in the taxonomy of engineering education and implied in multiple ABET student outcomes. Moreover, many introductory engineering courses worldwide have a component of programming or computational thinking. A preliminary study of enculturation to the engineering profession found that computational thinking was deemed a critical area of development at the early stages of instruction (Mendoza Diaz et al., 2018, 2019; Richard et al., 2016; Wickliff et al., 2018).

No existing computational thinking framework was found to fully meet the needs of engineers, based on the expertise of researchers at three different institutions and the aid of a comprehensive literature review. As a result, a revised version of a computational thinking diagnostic was developed and renamed the engineering computational thinking diagnostic (ECTD). The five computational thinking factors of the ECTD are (1) Abstraction, (2) Algorithmic Thinking and Programming, (3) Data Representation, Organization, and Analysis, (4) Decomposition, and (5) Impact of Computing.

This paper describes the development and revisions made to the ECTD using data collected from first-year engineering students at a Southwestern public university. The goal of the development of the ECTD is to capture the entry and exit skill levels of engineering students in an engineering program.

Development and Revisions of the ECTD

There have been several versions of the ECTD created over four years. Table 1 shows the timeline for the development of the ECTD, changes in the number of the questions, and the numbers of participants in the data used for psychometric analyses. The pilot version of a computational thinking diagnostic was developed in 2017 by the first author of this study. It was administered to first-year engineering students at a large Southwestern university in the United States. Descriptive analyses were conducted to check item difficulty and patterns of responses on the five multiple choices for each question.

Table 1. Development Process of the ECTD

Time	Version	No. of Questions	First Year Engineering Students
Fall 2017	ECTD pilot	15 questions	1,951 Total
Fall 2019	ECTD alpha	30 questions	373 Version A
		(15 each on ECTD-A and ECTD-B)	153 Version B
Spring 2020	ECTD beta	30 questions	480 Version A
Fall 2020		(15 each on ECTD-A and ECTD-B)	436 Version B
Spring 2021	ECTD gamma	20 questions	In data collection

In 2019, upon the receipt of the current NSF award, researchers at two other institutions joined the first author in a multi-institutional collaboration to refine the 15 items on the pilot version. More items were added to enable equal representation of the five computational thinking factors at each of three levels of difficulty: low, medium, and high difficulty (Mendoza Diaz et al., 2020). Two versions of the ECTD, called A and B, were created during a phase of development called ECTD alpha (i.e., six items for each computational thinking factor), which yielded 30 items in total (Mendoza Diaz et al., 2020). Then, the ECTD alpha A and B versions were administered to the first-year engineering students at the large Southwestern university in fall 2019 and a total of 526 students completed the ECTD alpha A and B.

An exploratory factor analysis (EFA) using Mplus 7.11 (Muthén & Muthén, 1998-2012) was conducted for each version. While there were five eigenvalues greater than 1.0 (Kaiser, 1960) and based on the point of inflection of the curve in the scree plot (Cattell, 1966), several negative correlation coefficients existed between some pairs of items. As positive correlations between items were desired, items with negative correlations with others needed improvement. The factor structure that was found was unexpected. There was only one factor indicated by seven items in the five-factor model and only one item was significantly loaded onto each of the other four factors for the ECTD alpha A version. Similarly, there was only one factor indicated by eight items in the five-factor model and only one or two items were significantly loaded onto each of three other factors for ECTD alpha B. Therefore, the team decided to undertake another round of item revision based on the results.

Several questions and their multiple-choice options of ECTD alpha versions A and B were revised as ECTD beta versions A and B. Due to the COVID-19 pandemic, the data collection procedure during Spring and Fall 2020 was not smooth and took more time to reach the number of participants necessary to conduct factor analyses. A total of 916 first-year engineering students at the large Southwestern university completed the ECTD beta versions A or B. While correlation coefficients between items were all positive, there were only four eigenvalues greater than 1.0 on both ECTD beta A and B versions. This indicates there were four independent factors measured by the instruments. Most items were loaded onto one factor and only one or two items loaded onto each of the other three factors. As the factor analysis results from the ECTD beta A and B versions were not the desired model that can reflect the five computational thinking factors, there was a need for another round of revisions.

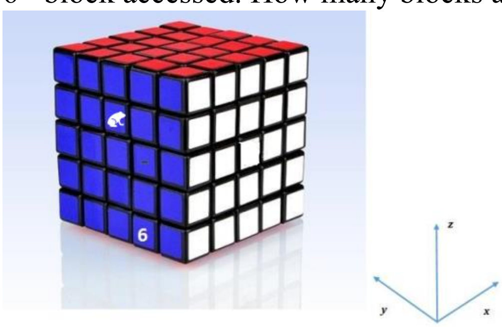
Instead of designing two compatible versions A and B, the 30 items from the beta versions of the ECTD were revisited for reanalyzes of content and face validity. The research team selected four best items to be indicators of each of the five constructs. Questions and five multiple-choice options were revised again to improve clarity and remove any cultural biases. This resulted in the creation of the ECTD gamma version A with 20 questions. Data collection using this version began in Spring 2021 and is currently in progress. If the five-factor model is statistically verified, then the team will create a second version patterned after the first (i.e., version B).

Table 2 shows an example of a revision done on the ECTD. After initially pool item statistics, the research team decided to retain the item as an example of the decomposition factor of computational thinking on later versions of the ECTD. To attempt statistical improvement, the team added a label of 26, hoping to guide the respondent to decomposing the problem to find the solution.

Table 2. Example of the Revision Process on the Decomposition Item

Fall of 2020 Decomposition Problem

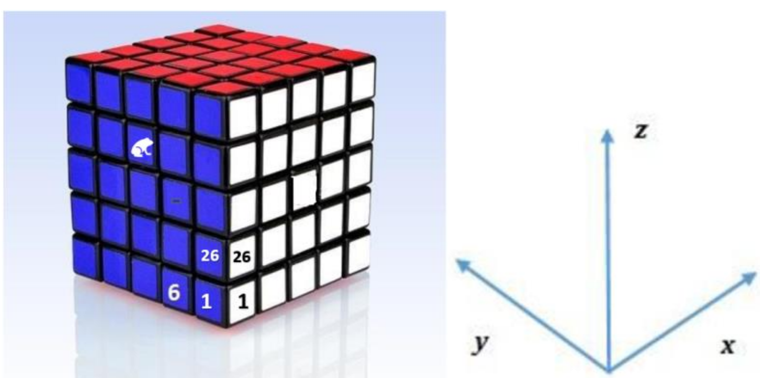
The Rubik's cube in the figure is composed of 5^3 (5 to the third power) blocks. A program counts the number of blocks traversed from the origin to the desired block by first traversing along the x-axis, then the y-axis, and finally the z-axis. For example, the block labeled 6 is the 6^{th} block accessed. How many blocks are traversed to get to the block with the frog icon?



a) 6 b) 11 c) 18 d) 78 **e) 86**

Spring of 2021 Decomposition Revised Problem

The Rubik's cube in the figure is composed of 125 blocks. A program counts the number of blocks from the origin of the coordinate system to a given block by counting the blocks along the x-axis, then along the y-axis, and finally along the z-axis. For example, the block labeled 6 is the sixth block counted and the block labeled 26 is the twenty-sixth block counted. How many blocks have been counted by the program when it arrives at the frog icon?



a) 6 b) 11 c) 18 d) 78 **e) 86**

Future Plans

Descriptive statistics on the data currently being collected will analyze student performance in computational thinking overall as well as by individual factor categories. The psychometric properties of the ECTD gamma will be investigated, such as whether the questions are good indicators of the designative five factors and properly categorized by item difficulty and discrimination. Student performance by factor categories will be evaluated by a variety of social identity groups (e.g. gender, self-identified race/ethnicity, first generation college attending).

Significance of the Study

A fully validated ECTD will help identify students that have strong entry-level skills in computational thinking, as well as identify other students that will require more academic development in this area. This could inform curriculum design for introductory engineering courses. For example, some institutions separate students with prior programming experience from those without it in beginning computer programming classes. An arrangement of this type might also be beneficial in entry-level engineering classes. Institutions might also discover the need for introductory computational thinking courses that previously were not included in the curriculum.

ECTD results will also allow instructors to understand how their student cohorts function across the broad areas of computational thinking. By using the results, the instructors can focus classroom and assessment activities to help students mature computational thinking factors that are less developed. The long-term impact would be classroom instruction that helps increase student self-efficacy and improve student enculturation into the engineering profession.

References

Cattell, R. B. (1966). The scree test for the number of factors. *Multivariate Behavioral Research*, *1*, 245-276.

Kaiser, H. F. (1960). The application of electronic computers to factor analysis. *Educational and Psychological Measurement*, *20*, 141-151.

Mendoza Diaz, N. M., Meier, R., Trytten, D., & Yoon, S. Y. (2020). Computational thinking growth during a first-year engineering course. *Proceedings of the IEEE Frontiers in Education (FIE) Annual Virtual Conference, Uppsala, Sweden.*

Mendoza Diaz, N. V., Yoon, S. Y., & Richard, J. C. (2019). Exploring enculturation in the first-year engineering program (Year III). *Proceedings of the 126th American Society for Engineering Education (ASEE) Annual Conference and Exposition, Tampa, FL, USA.*

Mendoza Diaz, N. V., Yoon, S. Y., Richard, J. C., & Wickliff, T. D. (2018). Exploring enculturation in the first-year engineering program (Year II). *Proceedings of the 125th American Society for Engineering Education (ASEE) Annual Conference and Exposition, Salt Lake City, UT, USA.*

Muthén, L. K., & Muthén, B. O. (1998-2012). *Mplus User's Guide (7th ed.)*. Los Angeles, CA: Muthén & Muthén.

Richard, J. C., Mendoza Diaz, N. V., Wickliff, T. D., & Yoon, S. Y. (2016). Enculturation of diverse students to the engineering practices through first-year engineering college experiences. *Proceedings of the 123rd American Society for Engineering Education (ASEE) Annual Conference and Exposition, New Orleans, LA, USA.* https://doi.org/10.18260/p.26956

Wickliff, T. D., Yoon, S. Y., Richard, J. C., & Mendoza Diaz, N. V. (2018). Changes in students' perceptions of their abilities on the ABET student outcomes to succeed during the first-year engineering program. *Proceedings of the 125th American Society for Engineering Education (ASEE) Annual Conference and Exposition, Salt Lake City, UT, USA.*