Supplementary File S1: Case Study Teachers

Qualitative case study research often includes "thick descriptions" of the context to elucidate the transferability of the results to other contexts (1). In this spirit, this supplementary file adds more depth of understanding about the teachers involved in this study and how they approached the enactment of the Energy in Your Environment (EYE) unit. The information below is based on data collected from end-of-unit teacher interviews along with research team observations from school visits. After describing each case study in more depth, similarities and differences across the cases are discussed.

1.1. Case Study School 1 - Faith

Faith was a junior high school teacher who taught at School 1. She has experience across a wide range of science disciplines and grade levels. She had a cumulative 20+ years of teaching experience. She began as a high school educator for 10 years before taking time off from teaching. She re-entered the field as a substitute teacher for 7 years until her permanent placement at School 1 teaching science and STEAM courses for 7th and 8th graders. Faith told us that she is the only junior high science teacher in her rural district. She worked with junior high students all day within her STEAM classes, science classes, and one computer class. The school did not have a set science curriculum, so Faith indicated that she had freedom and minimal involvement from administrators regarding her curriculum unit choices across all her classes. Faith structured her STEAM course as a project-based course, in which she prefers to have students work in groups during class. Faith prefers to give her students rigid guidelines and rules to follow during projects and tended to follow lessons closely as she preferred structured materials. Faith chose to implement EYE in her STEAM classes due to the engineering design project-based focus of EYE. Faith stated that she needed to do substantial independent research before teaching the unit to understand the building-energy connections and appreciated the teacher's content resources within the EYE unit.

Faith implemented the EYE unit at two different time points during the 2023-2024 school year. In her initial implementation, she stated she was "flying by the seat of my pants" and did not have time to implement the preparation-intensive investigations. However, she did enhance Module 4 by designing and implementing a math extension to calculate roof square feet for solar panels. For her second implementation, she stated that she felt better prepared to teach the unit and was able to include investigations that she omitted from her first iteration. In summarizing her students' experience of the EYE unit, Faith shared that she did not feel, during either implementation, that her students were interested in the content, but they enjoyed the online virtual simulations and the hands-on investigations. However, Faith felt that she, and her students, used their classroom as a learning lab in which they began to consider energy flow across the windows and walls. She discussed that she noticed many students referencing their classroom as they drew their systems models in the pre/post-tests. Overall, she thought that student knowledge increased throughout the unit, and their involvement in hands-on investigations and engineering design within teams was important to their learning. She planned to teach the unit again in the future and continue to consider extension activities she can incorporate into the unit.

1.2. Case Study School 2 - Charlotte

Charlotte was a junior high school teacher at School 2 for six years. She had taught 5-12th grade for 13 years. At the time of this study, she was co-teaching 7-8th graders with a colleague who specialized in English Language Arts (ELA). The two teachers planned together to teach EYE in their classrooms. However, the co-teacher had a maternity leave during the unit which made implementation more hectic for Charlotte. She also mentioned that many students were absent while she was teaching the unit, due to illness. Charlotte felt that both her co-teacher leaving on maternity leave and the number of student absences affected data collection as well as the student experience in the EYE unit. When discussing her district approach to curriculum and involvement in the classroom, Charlotte said that she has a great amount of freedom and choice when deciding what to teach. She used state science standards for her lesson planning but because of the flexibility in curriculum choice, she was also able to choose and implement lessons based on her students' needs. Charlotte said that she had never implemented a place-based unit in her classroom before but had experience with engineering design projects within her physical science lessons.

Her motivation to implement the EYE unit was to meet state science standards for thermal energy and electricity. At the beginning of the EYE unit, Charlotte invested time in ensuring her students had enough background knowledge and vocabulary. She found that her students did not have prior knowledge about energy flow within a building. To meet the needs of her students, she adapted and modified the unit in several ways such as including vocabulary checks, using station rotation in which students visited several different material areas in their classroom to investigate materials and energy flow, including connections to a recent water unit they had just completed, and using mixed ability student pairing. She discussed that due to student absences and her co-teacher's maternity leave, she had to skip some material intensive investigations. Due to technology limitations, the unit took more time to complete than she anticipated. However, Charlotte embraced the place-based nature of the EYE unit, including three building walks within the unit. The initial building walk was led by the school superintendent which focused on school design choices and focused on how those choices impacted the school utilities cost. In this building walk, students learned about energy efficient lighting upgrades to their school building. Charlotte led her students on two additional building walks focusing on light and thermal energy flow.

For engineering design (EYE Module 4), Charlotte chose to make engineering design more challenging for students, such as changing the required parameters of the building, lowering the construction budget, and/or increasing the energy efficiency requirements. In her interview, she shared her view that tightening the constraints made her students better problem solvers and made them more involved with the learning process of the EYE unit. Charlotte was impressed with the creativity and engagement her students exhibited in their final engineering design projects.

1.3. Case Study School 3 - Sophia

Sophia was a high school teacher at School 3 teaching two sections of 9th grade physical science. At the time of teaching this unit, she had seven years of high school teaching experience across grades 9-12, with five years of experience in the 9th grade. She discussed that there was another physical science teacher at School 3, but they did not co-plan together. Her school does not emphasize alignment to science standards, so Sophia used the Next Generation Science Standards (NGSS) for her planning. She also

discussed curricular freedom and discussed that she preferred creating her own teaching content. She sees her ability to be adaptive, innovative, and independent as a reason she is drawn to rural schools where teachers tend to have more freedom. During this study, Sophia was also an education doctoral student with the academic lab at the university where the EYE unit was developed. However, like the other case study teachers, she was new to building science. When asked about her background knowledge, she said "what teacher has the ability to design their own house and think about energy design? …so, it was really neat to think about."

Sophia discussed that she typically taught energy through the kinetic molecular theory and waves. She did not tend to include energy's impact on climate and the environment because she thought her students expressed a strong knowledge base in this area. When asked about previous experience teaching engineering design, she jokingly told the interviewer "okay, so I'm so bad about doing engineering because like when do I have time for that nonsense?" She shared her viewpoint that the engineering design approach seemed like an educational fad, and that she prefers to focus on science content. She thus de-emphasized career connections to engineering and architecture and focused more on energy content.

Sophia was initially concerned that the EYE unit would be redundant for her 9th grade students from what they learned in middle school. However, she noted that the unit provided her students a chance to solidify their understanding of energy, making the concept less abstract since it was grounded in an applied setting. She discussed that she tweaked nearly all of the EYE handouts before giving them to students (e.g., changing the wording of worksheet questions). She also used station rotations, instead of demonstrations, so that students could investigate materials and energy flow. To strengthen students' understanding of energy relationships, Sophia highlighted energy sources and their impact. For example, she held in-depth whole class discussions about the sun's impact on windows, since the sun is the source of energy that causes change. Sophia also placed a heavy emphasis on the systems models. For example, she elaborated on the building walk by asking her students to do additional sketching and discuss electrical, light, and thermal energy flows. She mentioned, however, that students were often burned out from drawing and worksheets by the end of the unit. She cited this as a reason for being disappointed with her students' post-tests. Her combination of investigations and reduced teacher talk allowed her to complete the unit in four weeks instead of six.

1.4. Key Similarities and Differences Between Case Studies

Taken together, the three case study teachers represent some of the natural variation that occurs in naturalistic settings for curricular enactment. All teachers expressed high levels of independence within their classrooms and supervisor support for their pedagogical choices. Sophia had the most advanced students (9th grade students in physical science), but Faith mentioned that her district tends to operate their junior high like a high school with how content was distributed across the grade levels. They worked with varying levels of students between grades 7-9 and brought their own knowledge and experience to EYE implementation. Each teacher adapted the unit to their unique students and pedagogical style -- and also to the unique freedoms and constraints of their school context. While Charlotte only had one small section of students, Faith and Sophia each had larger student sections in which EYE was taught. Faith was the only teacher who taught her two sections sequentially at different

points in the academic year, so that her second group of students may have had a stronger experience given her increased confidence in teaching the material.

They all needed to gain content knowledge prior to teaching the unit, and Sophia had the benefit of previous exposure to the unit as a doctoral student in the lab where EYE was developed. This exposure may have helped Sophia be nimbler with adapting content and moving faster through the unit. Charlotte expressed the most struggle in implementing the unit with her students, which resulted in emphasis on essential background knowledge and vocabulary. Sophia omitted the climate change and energy systems content in Module 1 since she perceived her students already had this background information. While Faith had a tendency toward following the materials, Charlotte and Sophia both backgrounded structure by adding and omitting unit material and bringing their own pedagogical knowledge to implementation. Where Faith and Charlotte both had previous experience with engineering design lessons, Sophia was skeptical of the engineering design framework and skewed the focus toward the science content rather than professional application. All three teachers taught EYE with place-based intention, each using their school facilities as teaching tools across unit themes. The teachers shared very similar comments about their students' experiences with the EYE unit. All teachers doubted the efficacy of the slide decks provided with the unit. All teachers mentioned that their students were most engaged on the days with hands-on investigations. Further, all teachers mentioned the student exhaustion with sketching by the end of the unit, which they believe may have negatively impacted the post-test data.

References

1. Creswell JW, Poth CN. Qualitative inquiry and research design: Choosing among five approaches. Sage publications; 2016.