# Innovations That Help People

## A Secondary School Computer Science Curriculum

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**Abstract:** In this research study we investigated the impact of a computer science (CS) curricular intervention on girls' interest in the topic. Our curriculum forefronts "Innovations That Help People" as a mode of broadening students' view of computer science. Our research focuses on real-life problems that require CS skills in order to be solved. Using a problem-based learning (PBL) framework, students are presented with practical problem situations and then are guided through a process of discovery and identification of possible solutions until a workable solution is achieved. The entire process is weaved around an ethical component (consequences and benefits of innovation). Data collection includes field notes, artifact interviews, and a focus group interview. Six students (3 girls) attending a private day school in a city in the Northeastern United States participated in the study. Preliminary results indicate that both girls and boys are motivated by the Innovations That Help People curricular approach.

## Introduction

### Current Women's Representation in STEM Careers

There is a dearth of women studying and/or entering the field of computer science (CS; National Science Foundation, 2015). This is true while computer and mathematical occupations are the fourth fastest-growing occupational group between 2014 and 2024, with a projected growth of 13.1%. The Bureau of Labor Statistics (BLS) projects adding 531,400 new jobs between 2014 and 2024 (BLS, 2015). Still, there remains a shortage of people able to fill software-development positions (BLS, 2012). Past research indicates that students begin developing and exploring future identities in middle and high school (Ji, Lapan, & Tate, 2004). Hence, it is important for students to be exposed to computer science education in these school years. Ironically, it is during these same years that many girls begin turning away from technology as an interest (Doerschuk, Liu, & Mann, 2007). One reason this turning away may occur is the strong perception, held by many, that technology and engineering are "male" disciplines (American Association of University Women [AAUW], 2010). In a recent study, Kelley and Bryan (2018) surveyed first-year engineering students to examine why fewer women choose engineering as a career. They discovered that while men do not consider the typical engineer to be masculine, many women do make this assumption.

### Communal Goals

Diekman, Brown, Johnston, and Clark (2010) explain that current research and policy in general focuses on aligning women and girls more closely with men and boys, specifically, increasing self-efficacy and the overall experience of women in STEM areas. However, those strategies do not seem to address all of the possible causes of why girls and women are not pursuing STEM fields. Diekman et al. state that STEM careers may be perceived as incompatible with the notion of communion, described as the desire to help and to be in the presence of others, and the action of putting others before one's self. Traditionally, men have been socialized to occupy leadership or breadwinner roles that usually include aspects of self-orientation and agency, whereas women have been socialized to opt for caretaking roles associated with aspects of communion. Diekman et al. posit that individuals may not be interested in a career if it appears to contradict their own socialized and internalized beliefs about the roles of men and women. Here we tie computer science directly to helping others as a means of overcoming socialized beliefs. We take a PBL approach to introducing CS projects focused on helping people.

### Problem-Based Learning (PBL)

Problem-based approaches are rooted in experience-based education (Savery, 2009). Learning research and theory suggest that when students learn by the experience of solving problems, students will learn both content as well as problem-solving strategies (Savery, 2009). In general terms, PBL can be defined as "the learning that results from the process of working toward the understanding or resolution of a problem" (Barrows & Tamblyn, 1980, p. 1). Ertmer and Simons (2006) propose the following two general goals for PBL: (a) to promote deep understanding of subject matter content while (b) simultaneously developing students' higher-order thinking.

In 2009, Walker and Leary published a meta-analysis of PBL accounting for implementation types, disciplines, and assessment levels. In their analysis, they identified the following four characteristics of PBL: (a) ill-structured problems are presented to students so there can be several causes as well as several correct answers, fostering students' exploration of multiple solution trajectories; (b) student-centered approach is crucial as students will self-assess and identify knowledge areas required to solve the problem(s); (c) teachers as facilitators or tutors rather than lecturers of knowledge; teachers' roles change drastically as they model learning processes that would enable students to solve their problem(s); and (d) educational experiences should be situated in real-life contexts; authenticity is mandatory in order to provide students with relevant and practical applications of their experiences. Our project, reported here, is based on these four characteristics through the curriculum we developed. The research question we addressed in this project is: Does a PBL-based curriculum focused on innovations that help people support girls' interest in computer science?

## Curriculum

The 12-week "Innovations That Help People" curriculum developed for this research project consisted of three distinct projects that introduced students to helping-technology innovations as they work in society: Move It!, Life Alert! and Self-Driving Cars! The participating students were guided to create functioning models of the innovation through use of the robotics materials and the Lego program. In addition, the curriculum also asks students to consider the ethical implications of innovation (e.g., job losses that are due to automation, legal implications of autonomous vehicles, etc.).

The curriculum consists of three problem/projects, including: (a) Move It!—getting a vehicle to autonomously go from point A to point B; (b) Life Alert!—developing a device that allows the elderly to live independently; and (c) Self-Driving Cars!—developing autonomous vehicles able to safely interact with other vehicles. The platform for programming and prototyping was Lego's *EV3 Mindstorms* education set. As a result, the requirements for each project were designed based on the capabilities and features of each Lego set.

Projects were designed to require increasingly sophisticated computational thinking. For example, Project 1 (Move It!) included concepts of algorithmic thinking, iterations, and debugging. Learning was scaffolded by providing students with unplugged programming exercises before programming their devices; students were asked to delineate all of the steps necessary to navigate from one corner of the classroom to the front door. Then students were paired up and assigned one Lego *Mindstorms* robotics kit per team. Each group was tasked with programming their device to go from point A to point B inside the classroom (points were marked using masking tape on the floor).

In addition, students had to measure the distance between objects in the classroom, decide on turning angles, and decide if their vehicles' motion will be determined by revolutions or by time. The class format included minilectures on programming and facilitator support for each team. Each student documented his or her progress in a research journal.

Project 2 (Life Alert!) introduced conditional statements, loops, and sensors. The challenge involved developing a device that could detect falls and produce an alert. This project helped students understand physics concepts such as acceleration, mass, angles, and axis. As a result, students had to perform measurements to determine which rate of acceleration represented a fall, while ignoring individuals sitting or bending down. Figure 1 presents a graph produced by the gyro sensors used in the project.

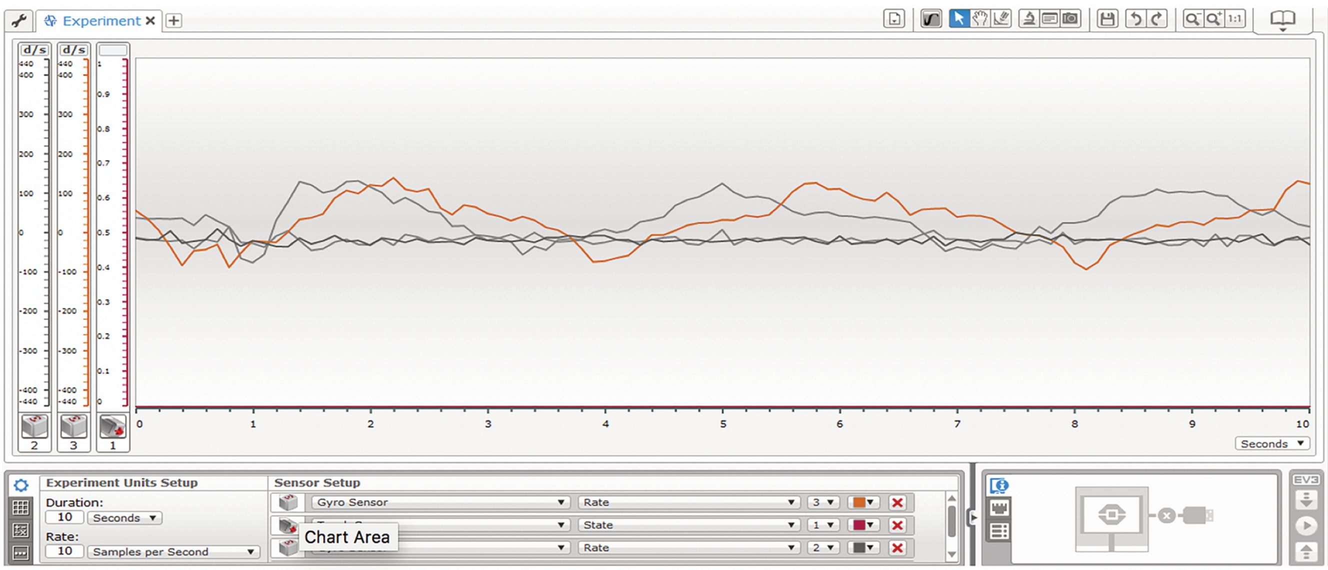


*Figure 1. Graphic represents rate of acceleration for two gyro sensors and one touch sensor state over 10 seconds.*

As a way to provide a real-life connection to the project, the class had a chance to interview an elderly person who recently had had an incident. Although the incident did not have major consequences, the person could have benefited from having a device like the one the students were developing. The interview provided students with an opportunity to refine their devices as well as produce a list of possible future features. At the end of the development stage, students had to present their projects in a "Shark Tank" presentation format, in which each team had a limited amount of time to pitch its product (project) to prospective investors.

Project 3 (Self-Driving Cars!), although similar to Project 1, involved developing autonomous vehicles that were able to safely interact with other objects or vehicles. This project introduced switches, parallel programming, and more complex loops. Because of the limitations of the Lego's sensors, students had to use color sensors to follow lines on the ground, while a second color sensor determined navigation. A third (proximity) sensor was also used, as a way for the vehicle to stop and go when there were objects in front of it. All three projects were accompanied by discussions about the ethics of innovation. Questions included: Are innovations always good? Does developing a device to empower the elderly translate into a more segregated and isolated society? What would happen to truck drivers' jobs if transporting goods became automated? Who is liable when there is an accident involving an autonomous vehicle; is it the driver (or owner), the car manufacturer, or the software developer?

## Methods

We took a case-study approach to this research project. The study was conducted at a private school in New England. The students in the course represent a convenience sample, as one of the authors is an administrator at the school. This sampling is a limitation of the study. The study took place in a course that was offered once a week in a three-hour block as part of the regular day curriculum. Students chose to take the class, and it counted toward one of three graduation requirements: math, science, or elective, depending upon what the student needed. The majority of students at the school are White, middle-class students, many of whose parents graduated from college; 40% of the students self-identify as part of the LGBTQ community, and three of the six research participants were girls.

Data collection included field notes, artifact interviews, and a focus group interview. Students' projects were assessed via an artifact interview, inspired by Brennan and Resnick's (2012) work. Artifact interviews helped us investigate how students thought about their programs, designs, and prototypes. Interviews were audio recorded. Interviews were thematically analyzed and field notes were summarized. Data was then reviewed to develop a characterization of the fidelity of the enactment and the efficacy of the curriculum for motivating interest and knowledge of CS for high school students.

To analyze the qualitative data for this study, we used the grounded theory approach (Charmaz & Belgrave, 2007), which implies initial coding, axial coding, and selective coding to inductively develop categories based on the data. We transcribed all of the interviews. Our unit of analysis was the complete utterance. We independently and iteratively reviewed each interview; after each review, our team met face-to-face to share codes and understanding based on the analysis of the entire research team. To facilitate the presentation of our findings, we provide: (a) a summary of themes related to student engagement; (b) individual student profiles created from the data; and (c) the themes that emerged in the focus group.

## Results

### Student Engagement

Several themes emerged from the data, including the motivation to take the class, prior programming experience (CS skills), communal/agentic goals, and acquisition of new skills. For example, while Susan, Lisa, and Maria (all females) had no prior computer science experience, all the boys (John, Mike, and Phil) had some degree of previous experience before the class. It is also important to emphasize that teenagers have different motivations to learn, or engage, in a specific task. In our study, some of the participants stated that they were motivated by communal goals (Lisa, Susan, John, Mike), while the remaining participants stated that their motivation was agentic (Maria and Phil). We found this breakdown interesting, as it indicates that the majority of students in this study have communal goals regardless of gender. Table 1 presents a summary of our qualitative findings.

| | **Susan** | **Lisa** | **Maria** | **John** | **Mike** | **Phil** |
|---|---|---|---|---|---|---|
| **Gender** | Female | Female | Female | Male | Male | Male |
| **Grade** | 12 | 12 | 12 | 11 | 11 | 12 |
| **Reason to take the class** | Volunteer | Mandatory | Volunteer | Volunteer | Volunteer | Volunteer |
| **Initial CS Skills** | No | No | No | Yes | Yes | Yes |
| **Communal/Agentic Goals** | Communal motivation | Communal motivation | Agentic motivation | Communal motivation | Communal motivation | Agentic motivation |
| **Post CS Skills** | CS skills improved | CS skills improved | CS skills did not improve | CS skills improved | CS skills improved | CS skills improved |

*Table 1. Student engagement with curriculum.*

## Students' Profiles

In this section, we will take a closer look at each of the student participants. Each profile includes information about each student's behaviors and motivations based on the artifact interviews, focus group, and field notes. The pseudonyms of the six students' profiles are Lisa, Susan, Maria, John, Mike, and Phil.

**Lisa.** Lisa is an 18-year-old White female student who has no experience with programming and robotics. At home she has several responsibilities, including doing laundry and cooking. During one of the class meetings, she underlined the fact that money is the main motivator for existing innovations. She stated that people would not invest money if the financial benefits were not apparent, even in those cases where the ideas can potentially be beneficial for society. During Project 2 Lisa was not paired with another student. Lisa was very interested in the design aspect of the device. She was the only participant who decided to make the device arm-wearable, similar to smartphone cases people use when exercising.

Throughout the intervention, field notes indicated that Lisa was more comfortable in the design of the device than the actual programming. During the artifact interview she explained her rationale for her design. She stated that because of the fact that she was working alone, she chose to focus in areas she is proficient with (arts and crafts). We observed that Lisa's head was lowered while the teacher presented information about programming. She sought program-writing help from the researchers observing the class, but she also expressed embarrassment in needing to do so.

Lisa was very interested in the idea of using technology to help senior citizens because of her personal experiences. She stated that her grandmother has been in situations where a life alert–like device would have been very useful.

> And the reason why I chose that is because like it's more like a personal reason because like H told you the story but like my grandma she wears a life alert. … She had the necklace but she never liked wearing it because

> it always got in her way. And so, she took it off but she accidentally sat on it. I think, so, I think it kind of makes it more personal.

Although programming is challenging for Lisa, she seems to realize how programming can be used to develop technologies aimed at helping people.

> I mean I think in the sense of like helping like disabled people. Like it can remind people take medication, or like if like an accident; or like if you were to kind of like the idea of like a smart car, like if you were an accident like me. There would be a device that like tells you that when emergency services like who you are and like that kind of thing.

It is important to highlight that Lisa's Project 2 included a feature that neither of the other two teams' projects did. Her device, after a fall was detected, would beep until a button was pressed. That way it involved a third party to come and check on the elderly people. She also made the device display a heart for a few seconds once the button was pressed,.

**Susan.** Susan is a 20-year-old White female student. She joined the class a couple of weeks later than its start date. At first, her engagement with the class was very limited, as her participation included several off-task behaviors during instruction. Susan noted that her parents would like her to pursue a career that included technology. Although Susan had no previous CS experience, she was able to acquire and demonstrate several basic CS skills as noted above in the description of the curriculum. In addition, Susan seemed to prefer collaborative group work rather than being passive during instructor-led activities. Susan was one of the most active participants, regardless of collaborative group affiliation. Susan became more interested in the class during the second half of the semester, evidenced by an increased level of communication with instructors and higher level of engagement with group partners.

**Maria.** Maria has a different profile from Lisa and Susan. She took the class because she needed a science credit to fulfill graduation requirements. Her participation in class was mixed; at times she would be very engaged while other times she would exhibit off-task behaviors. She stated that her motivation to innovate would be to make money, which we view as an agentic orientation. Like Lisa and Susan, Maria had no prior CS experience. She stated during the artifact interview and focus group how boring the entire class was to her. She also said how much she disliked building things. She explicitly stated that she preferred to play basketball. Maria did not learn much in the class.

**John.** John is a 16-year-old student who defines his race as *human*. He participated in all the sessions and had some CS programming experience. His CS skills became apparent, as described in our field notes: "John was able to begin programming his Lego device directly, rather than using the computer software version (the Lego device screen is about 2 inches by 2 inches)." On one occasion, he talked about how programming languages are the foundation of electronic games. He is interested in computer games and would like to learn how CS programming skills are used in the gaming industry.

Early in the semester, each student was asked to showcase an innovator. John chose Christopher Weaver, a video-game developer and CEO of a computer-game company. John was very passionate about the topic and focused on Mr. Weaver's achievements rather than describing his innovative contributions. The presentation was well researched.

During an innovation discussion, the following question was raised: Are innovations always good or always bad? John stated that innovations can have a negative impact on society. To support his thesis, he brought up the example of the atomic bomb.

**Phil.** Phil seemed to be intent on asking unrelated questions during class time, including talking about music, bitcoin, computer graphic cards, and so forth. He did not have extensive CS programming experience and tended to push school boundaries by introducing inappropriate topics. Phil's participation in class was inconsistent. He would tend to be very engaged during ethical conversations but appeared disengaged during building and coding activities. His team partners praised him for his creativity, specifically in situations where he made design or data-collection suggestions.

During Project 2, a guest speaker was invited to interact with the class. Phil was very engaged during the entire encounter; he asked relevant and thoughtful questions aimed at developing a better understanding of the difficulties of elderly people. Similar to Maria, he stated that his main motivation for developing innovations was to make money. Phil's level of CS skills improvement was marginal. However, he was able to explain CS concepts during the artifact interview and class interactions.

**Mike.** Mike was probably one of the most tech-savvy students in the classroom and was very interested in CS topics. He stated having a communal-goal inclination, specifically helping others. He was always ready to participate in class and was always engaged in discussions and group activities. There were times that he and his group partner would forgo going on class breaks so they could continue working on class assignments. During one of the sessions, when a researcher informed him about an impending break, he replied with: "I'm going to continue working. I hate to stop in the middle of something."

## Focus Group Themes

After the CS course was over, we convened a focus group with five of the students: three boys and two girls. During a 40-minute discussion, students shared their thoughts about the curriculum, specifically the projects they worked on, ideas about innovation, ethics, and most frequently, process. What quickly became obvious was the camaraderie and collaboration the students shared. The students enjoyed working together, even when they were paired with a partner they may not have liked before. When asked about working in pairs, they said they liked their partners:

> John: I quite liked the pairs I was in
>
> Mike: When I worked with Phil it was a bit better because he was better at building than I was, and he was more, you know, large minded. Like he was able to come up with things that I wouldn't have even thought of. Um but when I was working with John, me and him we're pretty close to the same
>
> John: ideas
>
> Mike: ideas and everything. So it wasn't as, it wasn't a breath of fresh air, I guess. Like working with Phil, and I never thought I'd say these words, working with Phil was like a breath of fresh air.

Furthermore, the students found success in using trial and error as a way to problem solve. Perhaps because the ground rules for the class began with "Fail: fail early, fail often," students knew they were not expected to succeed the first time around. They talked about the importance of using trial and error as a tool to create what they wanted, and as a way to test what they built. Additionally, the level of difficulty was important to them. Some students thought some of the projects were too easy and some thought they were too hard. Mike compared the class to being in a robotics club in his previous school. There he worked on only one part of the robotics; he was interested in programming and other students built the actual robot. Here he had to do both: design the robot and program it. In that way it was more challenging than simply programming.

Finally, the students talked about ethics. The discussion revolved around whether technology is good or bad.

> Mike: I have something. Hunting rifles, the original hunting rifles. People needed those to survive. It made hunting a lot easier for everyone. And it made getting food for yourself a lot easier
>
> John: Like whoever invented the cannon invented it for war.
>
> Mike: But the rifle was not made for war. This, yes it was used for war, that's its negative but a hunting rifle in itself was used for hunting, simply. So isn't it the gray line, because it in some cases it was used to keep people alive. But in other cases, to be used to take lives …

The students also discussed smartphones and social media. While they saw these technologies as important for communication, their downside relates to people "not knowing how to talk to each other." Hence these students attempted to understand the negative impact of technology.

## Discussion and Conclusion

Our PBL approach is novel in the sense that we use a communal-goal inclination as a way to attract girls to study computer science. As evidenced by the low number of women in computer science (and/or STEM) careers, there is a general understanding defined by Margolis and Fisher (2002) as: "Boys invent things, and girls use things boys invent." Girls are conditioned from an early age to be subservient to boys' choices. As those choices tend to be marked by societal expectations, men and women tend to choose career paths that align with society's classification of gender-based careers. We acknowledge that increasing the number of women in CS- or STEM-related careers is a multifaceted problem. The problem is rooted in the assumption that CS and STEM careers are not suitable for women (American Association of University Women (AAUW), 2010; Kelley & Bryan, 2018). As educators, we developed a curriculum that attempts to overcome this assumption by providing motivational factors to counter the narrative.

Our curriculum was originally designed to appeal to girls' communal goals (helping people) as a way to raise awareness that CS skills can be employed in a variety of situations. Once students opted into the course, we employed a PBL framework to foster intergender group work. Our intent was to provide an environment where boys and girls can work as equals, regardless of skill set or experience. In addition, we thought that an integrated STEM curriculum gives students affordances to participate, expanding ways for girls and boys to collaborate. Last, we also incorporated an ethics component as part of the innovation process. Incorporating ethics as part of the process seems to have triggered an additional level of passion from the students, while also developing more conscientious citizens. Our results so far are promising; both boys and girls in this study were interested in CS for communal goals, and most of the students gained in CS ability. Students can be motivated to learn computer science when instructional goals are communally inclined and presented in PBL format. Moreover, the students who had an agentic orientation also learned new CS skills. It is likely that both agentic and communal approaches are very worthwhile. Future research should focus on identifying entry points for a variety of students that include and go beyond communal and agentic orientations.

## References

American Association of University Women. (2010). *Why so few? Women in science technology engineering and mathematics*. Washington, DC: Author.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education.* New York, NY: Springer.

Brennan, K., & Resnick, M. (2012, April). *Using artifact-based interviews to study the development of computational thinking in interactive media design.* Paper presented at the annual meeting of the American Educational Research Association, Vancouver, BC, Canada.

Bureau of Labor Statistics. (2012). Employment outlook 2010-2020: Occupational employment projections to 2020. *Monthly Labor Review, January*. Retrieved from http://www.bls.gov/opub/mlr/2012/01/art5full.pdf

Bureau of Labor Statistics. (2015). Table 4. Employment by major occupational group, 2014 and projected 2024. *Economic News Release.* Retrieved from https://www.bls.gov/news.release/ecopro.t04.htm

Charmaz, K., & Belgrave, L. L. (2007). Grounded theory. In G. Ritzer (Ed.), *The Blackwell encyclopedia of sociology*. Wiley Online Library. doi:10.1002/9781405165518

Diekman, A. B., Brown, E. R., Johnston, A. M., & Clark, E. K. (2010). Seeking congruity between goals and roles: A new look at why women opt out of science, technology, engineering, and mathematics careers. *Psychological Science, 21*(8), 1051–1057.

Doerschuk, P., Liu, J., & Mann, J. (2007). Pilot summer camps in computing for middle school girls: From organization through assessment. *ACM SIGCSE Bulletin, Proceedings of the 12th Annual SIGCSE Conference on Innovation and Technology in Computer Science* Education (pp. 4-8). New York, NY: ACM.

Ertmer, P. A., & Simons, K. D. (2006). Jumping the PBL implementation hurdle: Supporting the efforts of K-12 teachers. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 40–54. https://doi.org/10.7771/1541-5015.1005

Ji, P. Y., Lapan, R., & Tate, K. (2004). Vocational interests and career efficacy expectations in relation to occupational sex-typing beliefs for eighth grade students [Electronic version]. *Journal of Career Development*, 31(2), 143–154.

Kelley, M. S., & Bryan, K. K. (2018). Gendered perceptions of typical engineers across specialties for engineering majors. *Gender and Education, 30*(1), 22–44. doi:http://dx.doi.org.silk.library.umass.edu/10.1080/09540253.2016.1262007

Margolis, J., & Fisher, A. (2002). *Unlocking the clubhouse: Women in computing*. Cambridge, MA: The MIT Press.

National Science Foundation. (2015). *Women, minorities and persons with disabilities in science and engineering 2015*. Alexandria, VA: National Center for Science and Engineering Statistics. Retrieved from http://www.nsf.gov/statistics/wmpd/

Savery, S. R. (2009). Problem-based approach to instruction. In C. M. Reigeluth & A. Carr-Chellman (Eds.), *Instructional-design theories and models* (Vol. III; pp.143–165).New York, NY: Routledge.

Walker, A., & Leary, H. (2009). A problem based learning meta analysis: Differences across problem types, implementation types, disciplines, and assessment levels. *Interdisciplinary Journal of Problem-Based Learning, 3*(1). https://doi.org/10.7771/1541-5015.1061