Training the Trainers:

Developing Robotics Faculty across Africa

An Interactive Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Submitted to:

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Abstract

Physically Active Youth (P.A.Y.), an afterschool program in Katutura, Namibia, provides extracurricular activities to children in underprivileged communities. Our goal was to provide educators at P.A.Y. with professional development resources to facilitate the implementation of a robotics curriculum. We created professional development, student interaction, and technical training resources. Through surveys and interviews, we found preferred teaching methods that increase student engagement in STEM topics providing new tools to teach and build STEM curricula for underprivileged Namibian youth.
Acknowledgements

We would like to thank all those who offered feedback, support, and encouragement throughout the course of the project. We would like to extend a special thank you to Professor Jermoh Kamara for preparing us for our IQP experience. We are incredibly grateful for Thuba Sibanda, Macveren Kapukare, and Maruen Kleopas from Physically Active Youth, who spent many hours after their long workdays to guide our work. Their dedication to their students inspired us to do our best work. We would also like to thank the Academic Technology Center, STEM Education Center, Robotics Engineering Department, and Mathematics and Science for sub-Saharan Africa at WPI for their continuous support over the course of our project. Finally, we would like to thank our advisors, Professors Nancy Burnham and Alexander Smith, for their guidance, enthusiasm, and feedback throughout this experience.
Executive Summary

Introduction

Katutura is a city in Namibia whose history has limited the students’ access to an equitable STEM curriculum. In 1990, Namibia gained independence from South Africa ending apartheid, laws that legalized racial segregation. The legacies of apartheid are still apparent in Namibia in many aspects, the greatest of those being in education. One organization in Namibia that attempts to address this deficit is Physically Active Youth (P.A.Y.) an afterschool program for students in Katutura that provides a “warm meal for the students” in addition to other programs that support the students. P.A.Y. uses a three pillar system of sport, educational success, and life-skills to provide learners with a holistic educational environment that serves the students.

One of the ways P.A.Y. hopes to contribute to the students’ life-skills and educational success is by implementing a robotics program. An educational robotics program will give the students of P.A.Y. the opportunity to develop their problem-solving skills and confidence to enter STEM fields. Technical careers are in increasing demand and many Namibians are unable to fill these roles as a result of the inadequate delivery of STEM topics. Many of the instructors understand the technical concepts necessary to develop these robots. However, there is a knowledge gap that exists between being able to comprehend STEM topics and being able to teach them. To stay current with global trends in STEM education, Namibia must provide the proper training for the instructors.
Methodology

The goal of our project was to provide P.A.Y. with professional development resources. We interviewed and surveyed educators in the greater Worcester area and in Namibia to get a full range of responses. These surveys and interview questions were targeted to find the answers to our four main research objectives:

- Determine the most efficient methods for designing a robotics curriculum,
- Understand and prioritize the skills needed to properly instruct an equitable robotics curriculum to be able to develop the best methods for interacting with students including competition and project-based learning in a flipped-classroom setting,
- Identify major difficulties in administering existing robotics curricula at P.A.Y., and
- Discover which resources are available to our sponsor P.A.Y. and gear our operations to developing the best outcome with the resources they have.

Our first objective was to understand and prioritize the skills needed to properly instruct an equitable robotics curriculum. To understand this topic, we surveyed educators about their experiences in the classroom. The questions for this survey focused on the issues educators faced in delivering STEM curriculum as well as how they teach to different learning styles & genders.

Our second research objective was to determine the most efficient methods of curriculum design. For this objective we surveyed Worcester educators and Worcester Polytechnic Institute (WPI) curriculum design experts. Through these interviews, we collected information on the best curriculum design techniques.

Our third research objective was to understand the difficulties administering existing robotics curricula. To answer this question, we interviewed the staff and educators at P.A.Y. Through these interviews, we began to understand the current working and educational environment at P.A.Y. We required more information to understand the resource availability at P.A.Y. These interviews were important for us to be able to fully grasp what areas of professional development P.A.Y. was missing and where we could expand.
Results

Through surveys and interviews of WPI faculty, local STEM educators and P.A.Y.’s teachers and administrators, we were able to identify strong curriculum development techniques, important instructional skills, challenges in administering a STEM program, and the role that resource availability plays in a robotics program.

To develop a strong curriculum, efficient methods must be chosen. These methods should have a solid structure for building lessons, while having the flexibility to allow for instructors to adapt on a lesson-to-lesson basis. To achieve this, we suggested the combination of multiple different curriculum development techniques. We found that a combination of backward design and the successive approximation model (SAM) is the most effective, as their strengths complimented each other and offset the other’s weaknesses.

We also identified the main skills needed to successfully teach a STEM curriculum. These skills include creativity, enthusiasm, and confidence when developing and delivering the material as well as the ability to connect STEM topics to everyday life and other disciplines. The combination of these makes material the most engaging, enticing students to interact with the curriculum and to pursue future interest in the topics. We also found that educators believe that it is very important to promote diversity and inclusivity in the classroom as students who feel accepted are more likely to come back and continue to engage with STEM topics.

Administering a STEM curriculum comes with its own set of challenges, including researching material, finding mentorship for both instructors and students, and making learning fun. The final challenge that surrounds P.A.Y.’s robotics program is the scarcity of resources. Through our research, we identified that the most effective way to use scarce resources was to apply the principles of backwards design. This is done by first determining what learning objectives are the most important for the students to reach, then allocating resources to obtain the materials needed to teach that topic. While there are many difficulties in administering a successful STEM curriculum, we were able to identify several ways in which P.A.Y. would be able to overcome those difficulties and have a successful program.
Conclusions and Recommendations

Our findings led to the development of the following deliverables and strategic recommendations for P.A.Y. Our primary recommendation to P.A.Y. is to integrate these deliverables into lesson design and instruction:

- Seven professional development videos on Newton’s laws, gear ratios, free body diagrams, torque, motors, sensors, and troubleshooting recommendations,
- Student Interaction Guide, and
- Professional Development Resource Guide.

To fill in gaps in technical knowledge, we developed seven videos on essential topics to prepare the educators at P.A.Y. with the skills and information needed to explain underlying concepts and to troubleshoot issues with the current kit hardware. We also created a Student Interaction Guide, which emphasizes best teaching practices for new educators, for them to use as they begin to work with students on the robotics lessons. Our team also developed resources on curriculum development, which allow instructors at P.A.Y. to begin to frame their own robotics lessons. These resources include a research guide, curriculum planning resources related to backward design and SAM, and a concept map of interdependent topics to determine a series to instruct curriculum concepts in.

Aside from using these training and reference materials, this project recommends conducting a fundraising campaign, allowing the robotics program to grow without hindering other programs in need of funding at P.A.Y.

For robotics specific investment, we recommend scaling up VEX IQ so that no more than three students must share a kit. Once this benchmark is reached, further robotics funding should target individual components (or potentially low-cost starter-kits) including Arduino microcontrollers like the ESP32 or single-board computers like the Raspberry Pi. Increasing computer lab capacity has some benefits to the robotics program but is not the most effective use of funds at this stage, since pair programming is an accepted teaching method with many of its own advantages. In summary, we recommend that P.A.Y. does the following:
● Include the training videos and *Student Interaction Guide* in trainings for new educators teaching in the robotics program,
● Use backward design and SAM to plan lessons, and to refer to the *Professional Development Resource Guide*, and
● Target investments at ensuring there are enough VEX IQ kits, then invest in low-cost microelectronic components to further diversify avenues for instruction.

For future partners or IQP teams working with P.A.Y., we recommend the following projects:
1. Fundraising and donor mapping for the robotics program,
2. Designing and procuring kits based on Arduino/Raspberry Pi, and
3. Designing and preparing a public competition.

All of these may be worked on in conjunction if necessary, as they all make big steps towards solidifying the robotics program. For similar projects working with other organizations, we recommend that researchers focus on gathering freely available resources, organizing them for educators, and testing implementation, with time to iterate on and revise the resource set.

Through our work with P.A.Y., we were able to prepare their robotics instructors to properly instruct an interdisciplinary curriculum that engages students in STEM.
## Authorship

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Chapter 1: Introduction

Throughout Africa, many schools and other education institutions have underdeveloped Science, Technology, Engineering and Mathematics (STEM) instruction. Improvements are being made by African governments in STEM education, but African nations are still falling behind compared to other education systems around the world (Tikly et al., 2018). Careers in STEM are in increasing demand, and many Africans are unable to fill these roles, due to inadequate delivery of a STEM education. The absence of proper background knowledge and supplies has led to teachers throughout the entire continent being ill-prepared to deliver an engaging and relevant STEM curriculum. These inadequacies can only be combated by providing high quality training to the educators, arming them with the tools to effectively teach the STEM topics.

Within the country of Namibia, educators face a deficiency when it comes to the technical and professional expertise required to successfully promote student engagement in STEM fields. Since gaining independence from South Africa in 1990, Namibia has been an ever-evolving and adapting nation. While the government has implemented progressive educational reforms, they have struggled to develop the background knowledge and preparedness of their educators. Consequently, Namibian educators do not have the training for the courses they are teaching, which has led to the spread of misinformation and lack of understanding in learners throughout the country. To stay current with global trends in STEM education, Namibia must provide the proper learning materials and training to their teachers. Education is only as good as its educators. If the teachers are not adequately prepared to teach the source material they are asked to cover, the learners in Namibia will not be prepared to fill available jobs in STEM fields.

Our project aimed to address the deficit of professional development for STEM instructors in Namibia, beginning with the instructors at Physically Active Youth (P.A.Y.), in Katutura, Namibia. Developing a training program for educators will combat the loss of interest and engagement of learners in the current STEM education system in Namibia. The deficit of professional development resources and support provided to educators is a major issue, as it often leaves them unqualified to implement curricula given to them by their school systems. After school programs, such as P.A.Y., fill that gap in knowledge for many learners in Namibia. This leaves after school educators trying to teach a wide variety of classes, and it is often too
much for one person to handle. Educators need more support in creating the building blocks for engaging classroom activities and comprehensive lesson plans.

This project worked, in collaboration with P.A.Y., to provide insights on how to further develop and scale resources to provide equitable robotics education opportunities. They are located in Katutura, just outside the capital of Namibia. P.A.Y. offerings help students improve their knowledge in STEM fields and helps students set goals for their futures. This project also worked with Mathematics and Science for Sub-Saharan Africa (MS4SSA) to expand from the implementation at P.A.Y. to sub-Saharan Africa at large. MS4SSA is an organization based at Worcester Polytechnic Institute (WPI) that aims to support primary and secondary school students’ education in STEM.

Our goal was to develop a scalable training program for STEM educators, starting in Namibia. The team created a training program that any educator, no matter their background, can implement within their classroom. The project created supplementary materials to aid in the administration of the robotics program at P.A.Y., which will act as a building block for MS4SSA to create a training program for educators throughout Africa. These materials include instructional videos, professional development resources, and a Student Interaction Guide, all aimed to arm educators with the proper knowledge and background to properly teach a STEM curriculum to learners in an engaging and productive fashion. The purpose of the project was to work together with P.A.Y. and MS4SSA to properly prepare educators for the classroom integration of a STEM curriculum.
Chapter 2: Background

To complete our project, we prioritized researching background knowledge on professional development in Africa, accessibility of STEM curriculum, what the current STEM and robotics community looked like in Africa, and the current teaching methods. We also sought to understand current professional development methods used and how they can be improved. To create STEM professional development materials, we required information on what educators had access to in regard to STEM. This was crucial because it was necessary to know what background knowledge they had and what information we needed to provide them.

We researched what the current robotics and STEM community throughout Africa looked like. Having a community that you can contact with questions and have as support could be meaningful for educators to be a part of. We lastly investigated a myriad of teaching methods, allowing us to provide P.A.Y. with options on how to continue to develop their robotics program.

2.1: Insufficient Professional Development for Namibian Educators

Although the educators in Namibia have the technical experience, they often do not have the training needed to properly teach the courses they are charged with instructing. Since gaining independence, the Namibian government has implemented many reforms throughout their previously segregated education systems. The consequences of apartheid are still seen in Namibia today through the shortage of proper education for disadvantaged native Namibians (Charter et al., 2020). As a result of Germany’s colonization of Namibia and the apartheid rule enforced by South Africa, the schools became quite segregated between white students and black students, especially in the more rural regions of the country (O’Sullivan, 2002). The segregation of education resulted in many under-qualified educators throughout the country, especially with regard to current STEM education, due to the lack of resources provided to the segregated communities. For example, today 60% of primary educators and 27% of secondary educators are defined as underqualified, meaning that they “have not completed at least three years of secondary education and post-secondary education with a focus in teaching” (Zeichner & Ndiamande, 2008). The Namibian government is attempting to combat this through multiple proposals, however, the majority of them are not being approved.
Many schools in Namibia are underfunded and have a great shortage of resources. These teaching conditions are not always taken into consideration when new reforms are implemented. One such instance was the implementation of an English curriculum into Namibian school systems in 1994. The English reforms were far beyond the capacity of the teachers that participated in the study (O’Sullivan, 2006). The result is that some teachers are unable to properly teach the lessons they are provided. Another issue with the current education system in Namibia is that the policy makers advocating for educational reform are often not educators themselves. This can often lead to the development of inefficient and ineffective methods of instruction that do not lead to success (O’Sullivan, 2006). Teachers are left without the necessary background or resources to properly implement the reforms that policy makers enact. Lesson plans and teacher education need to be taken into consideration for educators of all teaching levels and experience, as well as the varying working conditions each individual teacher faces. These programs should be developed alongside seasoned educators using researched-based methodologies and techniques that have been proven effective.

Teachers are often treated as messengers of information, leading to them not fully understanding the curriculum they are teaching. Without mastery of the content, the teachers cannot properly adapt lessons, develop engaging curriculum, or teach for different learning styles. As such, they lack the confidence to deviate from the provided teaching material. This approach is what leads to disengagement from learners, which interferes with deeper learning of the content by the students. In 2001, only 46% of secondary learners were able to meet the testing scores necessary to graduate to the next grade level (Zeichner and Ndimande 2008). Although teachers are delivering the core information to students by following a “script”, their lack of mastery with the content limits their ability to adapt content delivery in a way that meets a variety of learners’ needs. Without knowledge of the material, they teach students, educators may be unable to effectively answer student questions and present the information in a fun, engaging and memorable way so that students will fully grasp concepts and retain information.

In Namibia, some educators practice flipped classroom methods. Flipped classrooms move away from the traditional teacher-centered classroom, as seen in Figure 1, to learner-centered classrooms. This method of teaching incorporates learners’ life experience and previous knowledge as a basis for their curriculum. It uses natural and local resources as a way to challenge students instead of looking at it as a deficit. It also challenges the learner’s
participation, discussion and collaboration to facilitate a deeper understanding of the material for students (Zeichner & Ndimande, 2008). The flipped classroom method allows students to have a better understanding on how to apply what they learned in the classroom in a meaningful way to life situations. Although this learning method is an improvement for learners, it is difficult for educators in Namibia to teach due to their inexperience of using this method. This teaching method takes communication skills with the students that take a long time to facilitate and many educators need years of practice to perfect it.

![Figure 1: Namibian classroom (Tjihenuna, 2016)](image)

The team has created programs for the instructors at P.A.Y. to learn more about different teaching styles. The program that has been developed will combat the lack of resources and experience with helpful guidance and information needed to properly deploy a STEM curriculum in an engaging and interactive manner.
2.2: Limited Accessibility to Proper STEM Curricula in Namibia

One of the main obstacles facing Namibian educators in promoting student engagement is the lack of accessibility that the students have to a proper STEM curriculum, like the one previously drafted by students at WPI for P.A.Y. The main factors that contribute to a limited accessibility are gender inequity, lessened retention of STEM talent in Africa, and the price of the essential resources.

One of the main obstacles that the instructors have in developing this curriculum is that many of them do not have a formal education in STEM. In Africa, “58% of 15-17 year-olds are out of school” and only 6% of the world’s higher education bound adolescents are from sub-Saharan Africa (Barakabitze et al., 2019). To promote the retention of students in school, educators must utilize curricula and pedagogy to help engage the students best in STEM topics. By arming educators with the proper professional material and technical expertise, they can produce lessons that excite students every day to come to school. By creating material that sparks the students’ interest early on in their schooling (Figure 2), they may be more likely to pursue STEM fields as they continue their education and when they decide to enter the workforce.

Figure 2: Students in Africa (Internet Society, 2017).
I. Gender Inequity in STEM

Gender plays a big role when it comes to one’s access to a STEM education. The role of gender is especially prevalent in underprivileged communities where there are greater inequalities in educational resources.

Significantly fewer females in Africa are educated in STEM when compared to their male peers, as less than half of the girls in Namibia finish high school, compared to the national average of 67%. Instructors can combat this implicit bias through gender responsive training and engaging all genders equally. Gender responsive training refers to the application of techniques that an instructor can use to instruct students based on their gender. Gender responsive training targets a student’s skills and interests based on their gender. This could be expanded to engaging students’ interests and experiences, all the way to their individual learning style or how they best comprehend material. To best engage students in STEM fields, instructors should prioritize delivering material in a way that engages both genders equally.

One method that supports a gender responsive STEM education is providing young girls with role models in STEM. Experts assert that “the students, both girls and boys need to be exposed to female and male role models in order to cultivate the awareness of a mindset in which both women and men can study and perform in STEM fields” (Wang & Degol, 2017). Highlighting the potential that women have in STEM is essential to increasing engagement for all students, not just women.

One way that students can be introduced to female STEM role models is through a mentorship program developed by the instructors. In Africa, women have stated that “there are a lack of female mentors” and that the “absence of this support system is a big deterrent for women who may find themselves feeling isolated or diminished in the field” (Tikly et al., 2018). As a result, female students “may experience a ‘stereotype threat’, whereby they under-achieve in STEM subjects due to anxiety that they will conform to the stereotype that girls are bad at such subjects” (Tikly et al., 2018). Educators must emphasize the potential women have in technical fields and truly invest their time and effort to revert the implicit feelings these girls face because of societal norms. These role models in African countries can be found in “academic and government institutions as lecturers and research assistants”, differing greatly from where the male role models are found, specifically in positions of power & influence (Tikly et al., 2018). In
the development of an equitable robotics program, instructors should prioritize showing the students that women have previously succeeded in these fields to create a more inclusive classroom. The purpose of this is to show that both women and men have an equal capacity to succeed in STEM fields. However, there can only be so much mentorship that can exist when a great deal of the STEM talent in Namibia is being expatriated to different countries.

II. Retention of STEM Talent

Another aspect that contributes to the reduced access to a STEM education in Namibia is that technical talent from Namibia is being expatriated to other nations. Although globally people are receiving STEM degrees at a higher rate than they have in the last 10 years, these professionals are leaving their home countries in search of jobs elsewhere (Kigotho, 2018). In 2018, the African Union drafted the Revised Migration Policy Framework for Africa and Plan of Action which expresses the “urgent need to provide gainful employment, professional development and educational opportunities to qualified nationals in their home countries” (Kigotho, 2018). Furthermore, the African Union estimates that “there are over 100,000 expatriates who consume about 35% of development assistance to Africa” (Kigotho, 2018).

To retain individuals with a background in STEM, STEM program administrators must provide necessary assistance and the foundation to prosper in their home country. Lack of leadership in administrators as well, often contributes to educators’ greater sense of anxiety regarding developing their own curriculum. According to a study from Biputh and McKenna, in African countries, “administrators were rarely prepared to offer useful advice or provide an opportunity for learning.” Furthermore, the study also suggested that administrators did not create a space where instructors could have a one-on-one conversation with their supervisor (Tsotetsi & Mahlomaholo, 2015). Through a strong mentorship program where novice instructors can clearly state their needs and struggles, mentors and administrators can target the largest issues new teachers face. New educators need mentorship from advisors and senior educators; this dialogue and exchange of experiences is crucial to the development of STEM educators. To retain STEM talent in African countries, it is essential that the educators are provided with the proper support from administration.

Overall, the main factors that contribute to a lack of a successful STEM curriculum for students and instructors are gender inequity and decreased value in instructors as seen through
the deficit of professional materials and the greater problem of brain drain throughout Africa. Through this project gender inequity will be discussed through gender responsive training for instructors which will be pivotal in our design of a proper curriculum for educators.

2.3: State of the Robotics Community in sub-Saharan Africa

An active community of collaborators in the same field facilitates growth, builds excitement, and makes the field more accessible to all. In sub-Saharan Africa, there is a much smaller robotics community (in academia and industry) than in Europe, Asia or North America. However, many organizations from these regions are working to make their communities global by running similar events, competitions, and programs in sub-Saharan Africa. A combination of these outside efforts and growing efforts from the budding community students become more competent in STEM fields through revitalized public education in these topics.

I. Exposure and Familiarity

Exposure to robotics is essential to sparking the conversation about using it as a tool to teach technical fields. Without many accessible, robotics-focused university faculty, corporate interests, or third-party organizations nearby, administrators and teachers are not exposed to robots’ potential as interactive teaching tools. At the same time, educators have minimal local resources to draw on for lesson plans or activities, even if they have decided to incorporate robots. This leaves them unable to gauge their students’ interest in robotics, and leaves students unaware of opportunities in the field.

Access to robotics education programs and competitions has a network effect, seeding interest and resources can lead to a self-propelled growth of robotics curricula and resources for students of sub-Saharan Africa. In an examination of South Africa’s early developing robotics community, five benefits are discussed, including an increase in collaboration and funding opportunities, development of human capital, and more frequent publication, as well as reduced lead times (Stopforth et al., 2016). While any of these observed effects would be welcome in any community, efforts that target only one are more fragile and less likely to succeed. Through building more research, collaboration, and education opportunities, these effects become interdependent parts of the growth from establishing a self-motivated robotics community in the region.
Currently, Namibia faces difficulties with developing a community environment that will facilitate the development of robotics programs in the region. According to a joint report from the Namibian Ministry of Education and the UNESCO Office, Windhoek, the output of teachers from the main teaching university was much lower than the demand for new teachers throughout the country (2013). Teachers interested in introducing robots to their students are already stretched thin with responsibilities and have very few members of the research community or nearby teachers with experience in the subject that they can ask questions of. Learning new tools to run a lesson takes time teachers do not have, especially when starting a program like this with little to no financial, collaborative, or instructional assistance. In an annual education report from 2016, the National Institute for Educational Development (NIED) shows concern about the technical training that has been afforded to teachers now being asked to implement technical education in their classrooms.

The issue of Pre-service and in-service training of technical teachers should receive urgent attention, the follow up should be done as soon as possible so that NIED is not caught off guard when the implementation of Technical subjects kicks [sic] in 2017. The under-training of teachers is a critical piece holding back broader expansion of STEM education in Namibia. While external assistance can help bootstrap this growth, the NIED realizes this is not sustainable, and a vibrant technical education community will only come about via extended collaboration with the university system.

Technical Education and Training programs should be introduced in the institutions of higher learning so that experts are trained locally; the re-introduction of technical subjects is going to be a costly exercise, therefore the Ministry should avail sufficient funds in each region exclusively for the procurement of tools, equipment and materials in order to successfully implement technical subjects in 2017.

In the 2019-2020 academic year, the Namibia University of Science and Technology (NUST) had 12,610 students enrolled, with 1325 students enrolled in the Computing and Informatics program, and 1479 students enrolled in the Engineering program (Management Information and Institutional Research Office, 2020). While the growth may not be at its peak yet, government
efforts and the inspiration and drive of students exposed to STEM fields have started growing towards a self-sustaining, robust robotics community in Namibia. While formal education provides the foundation for this community, its strength comes from other sources, like competition programs and collaborative research which cause community members to meet and share knowledge.

II. Competitions and Networks

Robotics competitions are a significant part of the educational robotics community worldwide. The strength of competitions lies in the ability to bring together competitors from a wide geographic region at routine intervals, providing an experience for a diverse group of teams with many skillsets and backgrounds to meet, learn, and grow. By having a large community of teams working on the same problem, groups can learn from one another and boost the capabilities of teams with less knowledge, through communicating varied solutions to shared problems.

Researchers from AfrikaBot, a competition designed for African students, believe: “An effective STEM outreach requires more than just a cost-effective hardware kit and easy-to-learn software: it must also include online training resources and be supported by a community of educators” (Nel et al., 2017, p. 2). To realize this community, AfrikaBot undertook an eight-year effort to build a community. They created a website, YouTube channel, and gathered a network of supporting educators around the low-cost competition kit they made (Figure 3). Even after eight years of growth and developing a robotics community, AfrikaBot researchers still see human resources as the greatest challenge to establishing a program with longevity. Until there is a significant robotics community, including academics and industry sponsors, finding those with training or local access to training will be nearly impossible.
Narrowing in on the problem facing the expansion of robotics education, the R2T2 project in South Africa focused more on development of teaching methods than on typical robotics competition objectives. The goal of this project was to promote "North-South collaboration" and to help students become more enthused about robotics through competition and cooperation with their peers in another hemisphere (Mondada et al., 2016). Through having all participants remotely control robots, viewed over a live stream, the physical system design and costs associated with a kit like AfrikaBot could be removed. In this kit-less environment, they found that "the most challenging aspect of the teaching of robotic systems in South Africa is the methodology, with the sequential steps in the programming of the robots." (Mondada et al., 2016, p. 2) They attribute the difficulty of preparing students for writing these programs to the lack of expertise that teaching staff have with programming, and the involvement necessitated by administrative tasks, like configuring the development environment for students to use. However, the researchers also found value in having teachers of many backgrounds: “The broad spectrum of disciplines included in R2T2 created a situation where several coaches were not computer scientists… one can speculate that this also helped in getting a broader spectrum of participants, breaking the pattern of attracting only STEM-interested people” (Mondada et al., 2016, p. 12).

![Figure 4: FIRST Global Robotics Competition Arena (Ponce de Leon, 2019)](image-url)
Competitions also provide value through the amount of excitement they create. While designed to directly provide new skills, many competitions or workshops also provide inspiration, not only for the participants but spectators as well. A single good experience interacting with the robotics community can motivate students to further develop STEM skills by using resources they can seek out independently. While many countries in Africa have some degree of an emerging robotics community, Namibia has little to none. An article highlighting the impact of a robotic sensors workshop for university students says, “the reported educational robotics workshop is the only workshop hosted in Namibia…. which produced creative real robotics projects as well as fostered collaborations between universities and attracted other national and international collaborators on robotics.” (Shipepe et al., 2020, p. 1). A multi-pronged event such as this provides much more to the development of a community than an event that attempts to serve one of these purposes alone. To create even more value out of the event, “the workshop was not only to give participants a better understanding of modern robotics technologies but also to have them develop innovat[iv]e robotic systems that could contribute to Namibia’s socioeconomic growth.” (Shipepe et al., 2020, p. 1) By using the workshop as an incubator-type event, the business applications of robotics are forced to mind, and the motivation to deeply understand the underlying skills increases. The prospects of turning an idea into a business reveal the path to turn a skill into a livelihood.

As the global robotics community spreads into sub-Saharan Africa, opportunities to get more students and teachers involved continue to grow. These new roboticists will be able to further spread their skills and knowledge to learners in sub-Saharan Africa, but without structure and tested teaching methods, robotics education cannot become a significant, self-sustaining part of the education system. To use the incredible teaching tool of robotics, curricula must be developed and tested, to ensure best methods for teaching about the field are employed, making robotics accessible and enjoyable for students.

2.4: Curriculum Development Methods for Educators

Understanding curriculum development is an important precursor to creating training programs to implement STEM education. Curricula can be designed using different methods, with each focusing on different criteria to create an effective curriculum. It is important to understand the
components that make different techniques unique and how to use one or more techniques to create the strongest training program.

I. Definition of Curriculum Development

A curriculum is the information that an organization wants to teach in a given course (Definitions of Curriculum, n.d.). It consists of documents that define the content taught and the methods used (Weber, 2015). As such, how lessons are ultimately taught and the approaches to a topic throughout a course are determined by the curriculum (Definitions of Curriculum, n.d.). While curriculum is the content of a class, curriculum development is how organizations go from specific learning objectives to a fully refined curriculum that can be used to teach a topic.

Curriculum development is the process of deciding what topics are the most important to teach and the best methods to teach them. The terms “curriculum development” and “curriculum design” are used interchangeably. Curriculum Development is also about asking questions that determine what order information needs to be delivered in (Weber, 2017). The goal of curriculum design is to improve student learning (6 Non-Negotiables of Curriculum Design, 2016). Though curriculum is the overarching agenda and topics for a class, lesson planning and day-to-day scheduling is equally important. Without lesson planning, classes cannot hold their structure and the curricula will not be successfully conveyed to the students.

Curriculum should be centered around the students’ learning, not their ability to produce favorable test results. Students need to be actively involved in the learning process, not a passenger of the lesson. Administrators and educators are beginning to recognize this improves students’ education. By directly involving students in the learning process, educators are better able to identify what type of teaching works best for their students and adjust lesson plans accordingly (Nygaard et al., 2006). Anecdotal evidence of teachers giving students an active role in their own education shows they performed and understood the material better. For example, a teacher in a Chinese class allowed for students to have more time to connect with their projects. As such, the students were able to more fully develop their ideas and were more willing to take on bigger projects as they felt they could really do a good job with the project. Students were also given more personalized feedback by the teacher which enabled them to make the improvements that would take their projects to the next level (Lusardi, 2017). The students were able to excel when the curricula gave them more access to their education.
II. Curriculum Development Strategies

There are many ways to design a curriculum. We focused on five: the ADDIE model, backward design or understanding by design (UbD), the design thinking model, the successive approximation model (SAM), and the ARCS model. Each model goes through different steps to achieve student understanding, however, there are certain ideas that can be seen throughout some or all of the models. For all of the models the first step is understanding the learning targets and students’ skill level within the subject matter when entering the curricula. Each method also identifies some sort of assessment or end product that students complete at the end of the curriculum (Burnham, 2020). The methods differ in how they develop the intermediary steps and the order that they approach different parts of the curriculum design process. Regardless of the process that is being used, the material in any curriculum is guided by learning targets, and it is the role of curriculum designers to determine what those learning targets mean for students and how to best implement those targets into the curriculum (“6 non-negotiables of curriculum design”).

A. ADDIE Model

The most common curriculum development methodology is the ADDIE method (Burnham, 2020). ADDIE is an acronym, standing for analysis, design, development, implementation, and evaluation as illustrated in Figure 5. Analysis is the stage where the goals of the program are established and where “learners’ needs, including existing knowledge and skills,” are established (Burnham, 2020). During analysis, curriculum developers do research, “… collecting data and conducting interviews with various stakeholders and subject matter experts,” to thoroughly understand the learning objectives and content (DiFranza, 2020). The second stage is design, in which the framework of the curriculum is set. This step includes identifying specific learning objectives, content, and instructional strategies (Burnham, 2020). Design is often broken up into three sub-stages, setting an instructional goal, establishing key learning objectives, and identifying relevant content. By breaking the stage down, there is a clear progression to ensure that all critical information is conveyed to the students. Each sub-stage also gets narrower in scope as the curriculum develops (DiFranza, 2020). Development is when instructional materials are created from the content found in the design phase (Burnham, 2020). This is the stage where
“crucial decisions that will shape the final product,” are made such as what materials—texts, kits, technology—will be needed and what evaluation system will be used (DiFranza, 2020).

Stage four, implementation, is when key resources are tested and when the instructors of the course are giving the necessary training to teach the material (Burnham, 2020). By this point, all of the planning has been completed, and steps are being taken to bring the curriculum to the classroom (DiFranza, 2020). The final stage of the ADDIE method is evaluation, this is when the course instructors determine if the curriculum is effective (DiFranza, 2020). This stage is also used as a starting point to improve the curriculum based on results to increase student retention of the intended materials (DiFranza, 2020).

B. Backward Design Model

Backward Design is a model of curriculum development that focuses on in-depth understanding of learning goals (“The Fundamentals of Backward Planning,” 2019). Also known as understanding by design (UbD), it is comprised of three stages (Figure 6): identify desired results, determine acceptable evidence, and plan learning experiences and instruction (Burnham, 2020). UbD is set up to promote long term information retention and skill development by
determining how students will display mastery of a topic before creating the instructional material (“The Fundamentals of Backward Planning,” 2019).

Figure 6: The steps of backward design (Bowen, 2017)

In the first stage, curriculum designers determine learning goals based on what information is the most important to have a lasting understanding of (Bowen, 2017). Information should be broken down into three categories, knowledge, skills, and enduring understandings. In this case, knowledge is defined as the information students should be familiar with, skills being what students should be able to do, and enduring understanding being the big ideas that students should retain after completing the curriculum (“The Fundamentals of Backward Planning,” 2019). The second stage is when curriculum developers “determine how [they will] know if students have achieved [the] desired learning results” (“The Fundamentals of Backward Planning,” 2019). Assessments are broken into two types, performance tasks and other evidence. Performance tasks are “...larger assessments that coalesce various concepts and understandings like large projects or papers” (Bowen, 2017). While other evidence includes things like traditional homework, quizzes, and tests as well as self-assessments (Bowen, 2017). As the curriculum is developed around performance tasks that encompass multiple topics, students are required to use older information to inform new assignments in a way that traditional assessments would not require (“The Fundamentals of Backward Planning,” 2019). The final
stage is when lessons and learning activities are planned to address the goals initially identified (Burnham, 2020). This stage is not as structured as it is up to the curriculum developers and educators to determine what instruction and learning activities are required to achieve the initial goals (Bowen, 2017).

C. Design Thinking Model

The design thinking model of curriculum development focuses on understanding a learner’s needs and developing specific solutions to address them (Burnham, 2020). This model is composed of five stages: empathize, define, ideate, prototype, and test as seen in Figure 7 (Burnham, 2020). The first stage, empathize, requires the curriculum developer to “gain an empathic understanding of the problem [they] are trying to solve” (Friis Dam & Siang, 2021). The empathize stage is a research phase when as much information on the problem should be gathered. The second stage, define, is where the core problems are identified to be solved. Throughout this method, it is important to frame information in a human centric manner as to make the students the most important people in the curriculum (Friis Dam & Siang, 2021).

![Design Thinking: A 5 Stage Process](Image)

*Figure 7: The stages of the design thinking model (Friis Dam & Siang, 2021)*

The third stage, ideate, is when solutions should be brainstormed using a variety of techniques (Burnham, 2020). This gives many possibilities to address the problem and students will have access to the best possible materials. Prototyping is when specific solutions are designed and tested, this is where the teaching materials for the curriculum would be made.
Prototyping is also when feedback would be received from stakeholders to help determine if the materials being created successfully teach the curriculum (Willness & Bruni-Bossio, 2017). The final stage is to test, this is where the curriculum is implemented in the classroom and feedback is received from students (Burnham, 2020).

D. Successive Approximation Model

The successive approximation model, SAM, is a curriculum design method that was adopted from technical fields such as computer science. SAM consists of three iterative phases each consisting of several stages (Allen, n.d.). The three phases are preparation, iterative design, and iterative development as seen in Figure 8. The preparation phase gives stakeholders the opportunity to decide on the goals of the curriculum and how it will be delivered (Herrholtz, 2020). In this preparation phase the first outlines of the curriculum may even take shape. The next phase is the iterative design phase, which is made up of designing, prototyping, and evaluating stages that are repeated in an iterative manner (Allen, n.d.). The designing stage is where concepts from the preparation phase are given more substance and become concrete ideas. In the prototyping stage the designs are created and tested in a rough unfinished state so that they can be evaluated. This evaluation informs the curriculum designers as to which parts of the design work and which need to be redesigned (Herrholtz, 2020). Once the design has been evaluated, the designers will begin to do any redesigns that they see necessary, and this process is iterated until the curriculum is ready to go into development.

![Figure 8: The phases of the successive approximations model (Allen, n.d.)](image)

The final phase of SAM, the development phase, is a “constant loop of developing, implementing, and evaluating” the curriculum (Herrholtz, 2020). During this phase it is
important that there is always a usable section of the curriculum so that instructors and learners can interact with it and give feedback. As SAM was adopted from technical fields, there are additional release stages that come at the end of the development phase. The release stages are in place to give the curriculum developers an opportunity to make final changes to the curriculum if minor issues arise (Allen, n.d.). By this point in the model, there should not be any major flaws in the curriculum but the feedback in the release phase ensures that the developers did their jobs well.

E. ARCS Model

The final model for curriculum design that will be discussed is the ARCS model, a method that focuses on maintaining learner motivation throughout instruction (Burnham, 2020). ARCS is an acronym for attention, relevance, confidence, and satisfaction (Table 1). Material used needs to gain the learners’ attention, through real world examples, participation, and inquiry as well as through variable teaching methods (ARCS Model of Motivation, n.d.). The relevance of the information being presented needs to be made apparent using concrete examples (Burnham, 2020).
Table 1: Stages of the ARCS model of motivation (ARCS Model of Motivation, n.d.)

<table>
<thead>
<tr>
<th>Attention</th>
<th>Relevance</th>
<th>Confidence</th>
<th>Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceptual arousal</td>
<td>Goal orientation</td>
<td>Learning requirements</td>
<td>Intrinsic reinforcement</td>
</tr>
<tr>
<td>Provide novelty and surprise</td>
<td>Present objectives and useful purpose of instruction and specific methods for successful achievement</td>
<td>Inform students about learning and performance requirements and assessment criteria</td>
<td>Encourage and support intrinsic enjoyment of the learning experience</td>
</tr>
<tr>
<td>Inquiry arousal</td>
<td>Motive matching</td>
<td>Successful opportunities</td>
<td>Extrinsic rewards</td>
</tr>
<tr>
<td>Stimulate curiosity by posing questions or problems to solve</td>
<td>Match objectives to student needs and motives</td>
<td>Provide challenging and meaningful opportunities for successful learning</td>
<td>Provide positive reinforcement and motivational feedback</td>
</tr>
<tr>
<td>Variability</td>
<td>Familiarity</td>
<td>Personal responsibility</td>
<td>Equity</td>
</tr>
<tr>
<td>Incorporate a range of methods and media to meet students' varying needs</td>
<td>Present content in ways that are understandable and that related to the learners' experiences and values</td>
<td>Link learning success to students' personal effort and ability</td>
<td>Maintain consistent standards and consequences for success</td>
</tr>
</tbody>
</table>

Curriculum then needs to allow the learner to gain confidence with the material. This can be accomplished by setting learning requirements for students to meet, giving success opportunities where constructive feedback can be given, or providing students with control over their learning allowing them to focus on areas that they struggle in (ARCS Model of Motivation, n.d.). Finally, learners should feel a sense of satisfaction when they have learned the material, through both personal satisfaction and external reward, as a combination of both will encourage students to continue learning and increase internal motivation (ARCS Model of Motivation, n.d.).

III. Summary of Curriculum Development

Curriculum development is not a simple task, and a combination of different methods may be necessary to create the strongest possible curriculum. Efficient use of instructional design models creates an effective and engaging curriculum that will successfully convey the key information and skills from the course.

Having a set curriculum design method is something that gives courses structure and allows for them to flow smoothly. For inexperienced educators, having a guide to follow when
designing new lessons or updating existing curriculum gives them a structure that they can be confident in. Being confident in the structure of new material will likely lead to stronger materials and delivery. Additionally, having a guide will give more consistency to the material as it is developed in the same way every time.

2.5: Summary of Background

Through understanding the poor professional development in African countries, the obstacles leading to reduced accessibility of a STEM curriculum, the state of the robotics community in sub-Saharan Africa, and the best methods for curriculum design, we were able to more directly understand the core problems that limit robotics education in sub-Saharan Africa. These aspects were crucial for our project because professional development of instructors is pivotal to the engagement of students. Furthermore, accessibility of STEM educational resources is one of the major issues leading to reduced confidence for trainers delivering a STEM curriculum. Assessing the level of interaction in the existing community surrounding robotics and the current methods being used to design curriculum were important background knowledge for us, because they allowed us to capitalize on progress already made by P.A.Y. leaving us to fill in the gaps in these developing aspects of robotics education.
Chapter 3: Methodology

Our goal was to start the development of a scalable training program for STEM educators, beginning in Namibia. The instructors at P.A.Y. have technical experience from attending university in Namibia. However, to properly teach the lessons they also needed the right training to deliver the material. We prioritized arming educators with instruction on lesson planning, curriculum development, and classroom management. This program was made for and developed alongside the instructors at P.A.Y.

Over the course of the project, as described in Appendix D, we created technical support videos based on content found to be relevant to the curriculum that had been established by other WPI students, through last year’s project. We also designed a Professional Development Resource Guide that aids the educators at P.A.Y. to create their own lessons to increase the longevity & scalability of the project. In addition to this, we created a Student Interaction Guide (Appendix F) which highlights best methods of interacting with students through gender-responsive training, project-based learning, and competition-based projects.

To develop a complete training program for educators, we addressed the following objectives:

- Determine the most efficient methods for designing a robotics curriculum.
- Understand and prioritize the skills needed to properly instruct an equitable robotics curriculum and to be able to develop the best methods for interacting with students, including competition and project-based learning in a flipped-classroom setting.
- Evaluate preliminary content and iterate based on feedback.
- Discover which resources are available to our sponsor P.A.Y. and gear our operations to developing the best outcome with the resources they have.

3.1: Understand the Skills for Equitable Robotics Instruction

To develop the best material for the instructors, we created various surveys to understand the skills needed to develop a robotics curriculum. The first perspective that we considered is that of STEM educators from Worcester Public Schools & Massachusetts Academy of Math & Science. Their perspective was easily accessible through the WPI STEM Education Center, an
organization devoted to working with educators across the greater Worcester area. This organization provided us insight to our project as they are experts when it comes to STEM education. Our team contacted one of the program’s administrators who advised that we rely on questionnaires over interviews, due to the stress that the global pandemic is causing educators. With this suggestion, our team decided to develop a questionnaire based on previously published material and novel ideas developed by our team. The sample population of our questionnaires was K-12 educators that have at least five years teaching science, technology, and math in the Worcester area. We hoped to get at least 50 responses from STEM educators across the district. If the respondents expressed interest in a follow up interview, we then invited them to a recorded Zoom interview. After collecting the results from the survey, we anonymized all records.

In the initial questions of the survey, we asked for demographic information including their name, email, age, how many years they have taught STEM, and the age of the students they typically instruct (Gibbs et al., 2019). We asked these questions for multiple reasons, primarily, we wanted to assure that our surveys were being completed by a diverse group of instructors. We also wanted to examine the correlation between an educator's identity and their teaching style. From there, asked the instructor to analyze their strengths and weaknesses in delivering a STEM curriculum. We then followed by asking what professional development resources enabled those strengths and helped address their weaknesses. The purpose of asking these questions was to understand the knowledge gap that exists between being able to comprehend STEM topics and being able to teach them. Later, the survey asked the instructor if they have ever implemented gender-responsive instruction or taught specific to gender (Wang & Degol, 2017). This information was significant because women face many obstacles when entering STEM fields, and gender responsive training is one way to promote their entry into STEM. We then asked the teachers for advice for new instructors and their experience with student-teaching. We believed this information was important because we wanted to see how teachers believe they learn best from one another as our group was interested in developing a mentorship program for novice instructors at P.A.Y. Finally, we asked the educators if they would like to participate in a follow-up interview or provide more information to us in general.

Overall, the survey was 17 questions, with a mix of multiple-choice and open-ended questions. The survey was distributed by a contact from the WPI Center as a Qualtrics form. We
created charts and figures to better analyze and present the data. Teachers who were willing to participate in follow-up interviews were contacted to gain more insight into their responses. We prioritized interviewing teachers who had unique experiences, particularly in regard to gender responsive training, as their knowledge was less likely to be found elsewhere. We recorded these meetings with the consent of the participant and took minutes during the interviews. Through the analysis of this survey and the subsequent interviews we obtained a greater understanding of the skills that instructors needed to promote student’s engagement in STEM fields. Using these recommendations from STEM educators in the greater Worcester area, we provided the facilitators at P.A.Y. with the proper skills to promote this advancement in STEM fields.

3.2: Evaluate Preliminary Content and Iterate on Feedback

To create a set of high-quality training and instructional resources for educators, we used feedback from survey respondents who watched an early version of one of our instructional videos. The video covers free body diagrams, and is intended for instructors with or without a background knowledge of physics (assuming they have watched the previous Newton’s Laws video). Previous experience with free body diagrams was measured, to allow results to be more representative of the targeted educators, whose experience also may fall anywhere in this wide range.

We used feedback from the survey to strengthen techniques and content in the free body diagram video, and general responses on the survey enabled improvements on the other videos. The pattern of iteration: developing, evaluating, and redesigning, mirrors the approach of many curriculum development models. By testing the quality of the in-development lessons, we enabled insights to be used to improve contextualization, pacing, and word choice in the videos, among other important qualities.

In addition to the improvements to the resources and materials developed, this research objective also served as a demonstration of the validity and effectiveness of iterative design methods. By requesting this feedback on the educational programming, we planned to teach with, we were able to make meaningful improvements, showing the value of iterative design for curricula.
3.3: Determine the Most Efficient Methods of Curriculum Design

To better understand what curriculum design methods are the most effective, the team consulted teaching and professional development experts. We interviewed several curriculum design experts from WPI. Additionally, we surveyed WPI faculty and Worcester high school STEM educators.

We conducted these interviews via Zoom with the goal of understanding how curriculum design is used. We asked the experts about the methodology of various design techniques that were researched to gain an understanding of how to create professional development materials for each technique. We also asked about the relevance of various methods in the survey in Appendix A. Using feedback on which methods teachers found to be most relevant, we adjusted the survey to provide the most valuable and relevant feedback. The main adjustment we made was to reorder the methods in the survey so that if someone decided not to complete the survey, stopping midway through, they would have seen and responded to the most common and applicable techniques. Additionally, we added a small excerpt from the background on each method to the start of each section to allow teachers to identify a method that they may not have known by name.

The data gathered from the interviews was organized in a series of documents in which key points from each interview were highlighted to indicate their importance and subject matter. Across documents, the data were then aligned to see what data supported other information from other interviews. When data across several interviews did not support the same conclusions, they were then evaluated by the number of different sources that said the same thing and what level of expertise and experience the different sources had.

The survey participants were first questioned regarding the techniques that they use to develop curriculum, as well as the other methods they have been exposed to. Questions included multiple choice, rank order, and open response questions with the intent of gaining a fuller understanding of why certain methods may be preferred. The survey, which can be seen in Appendix A, was 20 questions in length with most of the questions being about specific experiences of using the various methods of curriculum design. We made the survey using Qualtrics and then distributed through previously established contacts between WPI and STEM.
educators. Our goal was to gauge the amount of experience educators have with different methods as well as the quality of that experience relative to other methods.

By using these questions for each of the curriculum design methods discussed above (Background Section 4.2), we established a holistic understanding of the usages of each method. From there, we asked additional questions as to the strengths and weaknesses of various methods in an open-ended format to allow the teachers to evaluate the strengths and weaknesses of each method. To get a well-rounded sample of educators, the survey was distributed to all faculty at WPI and as many high school STEM educators as we could contact. The estimated sample size was 10-15 high school teachers. By the end of survey collection, a total of 7 surveys were filled out. This made the sample sufficiently large to identify and analyze trends.

Data from the survey were organized in the spreadsheet from Qualtrics and then was later transferred into a spreadsheet that allowed for data to be manipulated to analyze trends. Data were plotted to understand trends in data sets that did not have clear trends from looking at the answers alone. Data from long-answer questions were analyzed through finding key recurring points and analyzing why these points were recurring.

From this analysis, we determined five different criteria most pertinent to determining the most efficient curriculum development method and used them to evaluate each curriculum design method. The five criteria were:

- Iterability of the process,
- Availability of tools for the method,
- Usability of the method,
- Effectiveness of the method, as stated by curriculum design professionals and teachers, and
- Recency of the curriculum development method.

Each criterion’s weighting was determined from the amount of emphasis that WPI curriculum development experts put on the importance of each in interviews. The effectiveness of each method was given the highest weighting as ultimately the goal of each technique is to design the best curriculum and lessons on a topic. The availability of tools for the methods and to what extent the process was iterative were given equal weighting as both assure that the staff does not have to develop new materials every year. This is because iterative methods are always in motion allowing different parts to be revised as seen fit by the instructors. The availability of external
resources means that more time can be devoted to the students and the course material. The ease of use had a smaller weight because each method can be learned over time, however we still wanted a technique that the instructors would be able to learn as quickly as possible. The recency of each method had the lowest weighting as it was discussed in relation to other criteria such as whether or not the technique was iterative and the availability of materials. However, it still did influence other factors like how much new material would be released surrounding the method.

3.4: Assess Difficulties Administering Existing Robotics Curricula

To understand the difficulties that P.A.Y. encounters when implementing curriculum, we collected information on their current working environment. This information was crucial when designing the robotics curriculum for P.A.Y. By understanding the issues that have previously arisen from implementation of past curricula, our team created a training program that combats these difficulties and better prepares the educators in the subjects they teach. We collected information on the administration of the Namibian school system. This information provided our team with insight into how professional development programs are implemented in their school systems, and on how to convey the needed information to educators in the proper manner.

To obtain this information, we conducted interviews with the instructors at P.A.Y. via Zoom. The interviews were between 30 and 60 minutes. We recorded the interviews with the consent of participants, and minutes were taken.

The team asked a series of questions that can be found in Appendix C. These questions covered the educators past experiences with professional development and their current teaching environment. For educators at P.A.Y., we also asked questions about their experience with the curriculum that they currently use. The perspective of these educators was of the most importance, as they not only know what works for them, but they also have a deeper understanding of how Namibian students learn best.

The initial questions focused on the basic demographics and the educator’s background. The line of questioning then moved into more specifics regarding the previously implemented STEM curriculum. These questions helped us fully grasp how the teachers at P.A.Y. absorb the information they are teaching and how they approach delivering their lessons to students. Administrators were asked similar questions, tailored more towards their role in implementing professional development programs throughout their educational institutions. This perspective
provided the team more insight into how educators receive training and how goals for these training sessions are prioritized. We utilized the information from these interviews and used it to create a more accurate, specific program targeted at filling in the gaps with current instruction.

3.5: Assess Resources Available

The limited access to teaching resources is one of the critical problems facing the instructors at P.A.Y. Frequently, these subjects are taught best with hands-on projects, but the materials needed are extremely costly. Preparing educators on product ecosystems, software toolchains, and troubleshooting resources that will not be relevant to their instructional content would be wasteful, should they settle on using different items due to cost or access limitations. To ensure that the training we provide is relevant to the organization’s available resources, we tailored our deliverables for educators to better prepare themselves for situations likely to occur in their classrooms. To direct training towards the resources available, we opened a dialogue with educators about the resources in their classrooms and communities.

We interviewed the educators at P.A.Y. to understand the resources available, from access to computers and the internet to building materials, circuitry, and actuators. Surveying with direct questions such as, “How many computers are available to your students, and what are their specifications?” yielded some useful responses, however, a one-off communication will likely lead to relevant details being left out. To ensure that teaching resources provided match the physical resources that are already in place or are easily accessible, multiple conversations were necessary. These conversations helped to qualify specific details of the resource constraints, as well as to find opportunities available to expand or complement existing resources. Throughout the development of our deliverables, we remained in contact to further gauge which resources needed the most attention. By keeping an open line of communication including, documentation, project ideas, lesson plans, and recommendations for other resources were tailored to the educators’ available resources.

We established and maintained contact via email, though for in-depth conversations about the tools and resources at instructors’ disposal, we used Zoom. This enabled us to conduct interviews and subsequent check-in meetings, in addition to making recordings of the interviews for further analysis. If, when asked, the interviewee was not comfortable with having a video or audio recording made, we fell back to simple notetaking, making them aware that their
participation in the interview was voluntary. We used these interviews in the creation of video instructions for suggested lessons and projects, as well as in the documentation of best and most applicable teaching methods. Through interviews and check-ins, we ensured existing resources were the basis for the new material to be included in the videos, *Student Interaction Guide*, and *Professional Development Resource Guide*.

### 3.6: Limitations

There are several advantages & disadvantages that came from using Qualtrics surveys to gather information on teaching a STEM curriculum and types of curriculum design. Two benefits of Qualtrics surveys are that, when compared to a paper copy, they can easily be organized, and the responses can be plotted within the website. A main disadvantage of Qualtrics surveys is that they are distributed as a link. In comparison to a physical survey, a link is easier to lose in the many emails teachers receive. In addition to this, a survey cannot provide the same information that a formal interview can provide, due to the inability to follow-up and ask clarifying questions. Another limitation of the survey was that since it was being distributed by administrators, educators may have been less forthcoming about lack of support from leadership in fear of retaliation.

Limiting factors of these surveys included time and reach. Due to the questions collecting as much information as possible, the surveys likely took over 15 minutes to complete, which may have reduced the number of responses, or caused them to give less complete responses. Additionally, because these were longer surveys with long form responses, the data from open ended questions took more time to analyze before it could be effectively used. Another major limiting factor was reach. If the surveys did not reach a wide enough range of educators, responses may have been repetitive and not insightful due to the similarities of the answers.

Potential limitations of the interviews were the small number of subjects we had, which may have caused our results to not represent the experiences of most Namibian educators. Another disadvantage that arose from using Zoom was that it requires a stable internet connection which was not easily accessible to all participants. It also required a device that supports Zoom, such as a computer or mobile device, which potential participants may not have had access to. Lastly, our team only had background knowledge of Western education systems, so the questions may have been unduly biased towards Western styles or may have left out
important questions that western learners may not consider. One advantage of a recorded Zoom interview is that one can go back and watch it after it has been conducted to see or hear things not picked up on the first time. However, the results from the interview are not automatically coded or summarized, as with the data in the Qualtrics Survey. All audio and video collected during this project will be deleted upon its completion. Participation in the surveys and interviews was completely voluntary, and a consent form was distributed along with the surveys before the survey was conducted. No personal information has been reported upon, only the data received.

3.7: Summary of Methodology

To understand the best practices of delivering a STEM curriculum through student interaction and curriculum design our group interviewed and surveyed many educators and administrators of STEM programs. We also applied these same strategies to identifying the difficulties of administering a robotics curriculum and how resources influence that as well. By interviewing and surveying stakeholders, experts, and instructors, our team was able to provide definitive recommendations to our sponsor, P.A.Y.
Chapter 4: Results

To achieve our team’s goal of starting a scalable professional development program for the robotics instructors at P.A.Y., we prioritized learning from the experience of seasoned professionals to understand the best practices for delivering a STEM curriculum. Our team researched the issues STEM educators face in different programs. Primarily, our team accomplished this by utilizing our contacts at the WPI STEM center to contact experts in instructional design and from there these contacts distributed our surveys across the Worcester Public School system. We also interviewed an administrator at a STEM focused school, to understand the administration of teachers who deliver technical subjects.

It was important to prioritize the experience of certified teachers because they have extensive training on technical content and also understand the best methods for interacting with students. From there, we expanded our project by contacting local after school robotics programs in the New England area. Our team interviewed the administrators and instructors to learn how they teach supplementary educational topics. Finally, we interviewed our sponsors to understand the issues they face teaching students and the constraints that resources have on a program like P.A.Y. We collected a broad selection of perspectives on how to administer professional development and training materials to prepare educators to teach a robotics curriculum. Compiling and analyzing this information guided the creation of materials for P.A.Y., to implement these best practices to prepare instructors to teach robotics.

4.1: Skills Needed to Properly Instruct a Robotics Curriculum

By completing our first objective of understanding the skills needed to teach a successful robotics program, we gained insight on teachers’ experience in delivering a STEM curriculum, specifically through their interaction with the students. Our team came to this understanding by collecting advice on the facilitation of STEM lessons from experienced teachers.

Over the course of three weeks, the WPI STEM Center distributed the survey using Qualtrics to gain the responses from instructors in the greater Worcester area. With the questionnaires, our group learned a great deal of information about instructing STEM topics and the best practices for delivering an interdisciplinary curriculum. Our respondents’ different ages, gender, and years of experience in instructing created a diverse pool of varied information.
When identifying their strengths in delivering a STEM curriculum, 38% of the educators stated that their strengths are their passion and their engaging/creative delivery of lessons (Figure 9). In our Student Interaction Guide we promote instructors to make fun lessons and we also made our videos fun and interactive as well. Twenty-five percent of the educators shared their main asset was their enthusiasm for teaching technical topics. The instructors who completed this survey joined this profession because of their love for STEM. The volunteers at P.A.Y. may not have a passion or interest in STEM, however, to best serve the students, as illustrated by the data, they should be enthusiastic about presenting the material. Twelve percent of the educators highlighted that to promote the advancement of the students in STEM, the lessons should be relatable to the day-to-day work of the local people (Figure 9). One respondent highlighted that this “provides greater instructional access to prior knowledge and quality scaffolding of instruction.” This data truly shows that students want to utilize the knowledge that they learn in technical lessons to benefit their society. Furthermore, if an instructor appeals to their prior knowledge, students will be able to apply it in STEM lessons. In our Student Interaction Guide, our group details this in detail as a product of interdisciplinary lessons. Understanding the instructors’ perceived strengths in delivering a STEM curriculum was important to the development of our project because it showed what the instructors prioritize when teaching.
Fifty percent of all instructors shared their main perceived weakness was allocating sufficient time for planning instruction (Figure 10). Over the course of the last year, the respondents of the survey have been teaching during Covid-19, which could contribute to why so many instructors provided this sentiment. Instructors have had to change the way they have taught throughout their entire career; however, time management is still a crucial aspect to education in general. The other weaknesses the instructors had included lack of supplies, lack of experience, and the disconnect between STEM and humanities as the instructors’ perceived weakness in preparing a STEM curriculum. Through our background research, our group is not surprised that supplies are a major weakness in instructing a STEM curriculum, as seen from the price of proper materials like VEX robotics kits. An instructor who highlighted that they had less than ten years of instruction stated that lack of experience deterred the delivery of their lessons. Finally, the instructor who stated that the disconnect between STEM & humanities topics was the same instructor who highlighted their strength was being able to build off the students’ prior knowledge. Our team used instructors’ perceived weaknesses to find opportunities to reinforce these skills, through the deliverables and training material we created.

![Instructors' Weaknesses in Preparing & Delivering a STEM Curriculum](image)

*Figure 10: STEM Instructors’ Weaknesses in Preparing & Delivering a STEM Curriculum*

The next major subsection of the survey gauged the respondent on their preferred method of professional development. We asked each educator which professional development resources helped them become better teachers. The majority of the respondents highlighted that previously
developed lesson plans, instructional videos, and information provided by administration were of the most use to them. This knowledge not only helped us provide recommendations for P.A.Y., but it also helped us structure our material. Our team decided to make instructional videos as a result of many instructors stating it helped them the most. Many educators also reported that the best resources are other, more experienced STEM teachers. One instructor said that by “talking to other teachers you can get ideas for new projects, ways to improve current projects, or other ideas to improve the rigor and make the projects more authentic.” From this, our team concluded that instructors believe that STEM instructors learn best from those around them, therefore our team used this to make recommendations on a mentorship program at P.A.Y. Another teacher stated that the best professional development resources are “lessons that can be modified...that can have worksheets, materials, PowerPoints, and descriptions” with hands-on instruction and an ability to try it out for yourself. With time being the greatest concern for teachers, the focus for reducing common weaknesses falls on time management. Through our research, it became evident that providing instructors with time-saving methods to do the same work would provide the most value, by reducing the number one perceived weakness.

The next subsection of our questionnaire asked the respondents what advice they would give to new instructors (Figure 11). One third of the respondents reinforced the previous statement: that educators should try all activities prior to implementation in the classroom. As a result, we expressed this same sentiment in our technical training videos. Instructors who had greater than 10 years of teaching experience, therefore, they most likely have learned this from failure of implementation. Another third stated that lessons should be made relatable to the lives of the students, through an interdisciplinary curriculum that uses the student’s prior knowledge. When providing advice for new educators one of the respondents expressed that instructors should “be clear with the students, no sarcasm, no figurative language, no trick questions and to check in with them frequently to ask if they need anything that is not being currently offered.” Another educator later asserted to “be honest, build trust, and the rest will follow.” We asked these veteran instructors the advice they would give to new instructors because we wanted to
make our program accessible to educators with a varying level of experience in instructing students.

Figure 11: Mentorship Among STEM Instructors, Best Practices for New Instructors

When we asked about the significance of diversity when teaching STEM topics, many of the respondents approached the question in a different way (Figure 12). A third of the respondents expressed that catering to a “diversity of learning styles is critical to helping students gain a stronger understanding of STEM topics.” Using this data, our team researched different learning styles that students typically use, and we found the correlation between learning styles and gender. One instructor later expressed that by “bringing a group of students with [different] backgrounds adds to the quality of STEM conversations in the classroom.” Another facet that our team found interesting was that those who highlighted those with the greatest number of years instructing did not highlight gender in the classroom, one of them even going as far to say that she “treats them the same.” While the sentiment of equality is expressed, this perspective fails to realize that there are differences in learning styles, lived experience, and relevant metaphors that must be accounted for. Without sensitivity to the differences of the students in the classroom, instructors teach for the “average” student, a description met by none of the actual pupils before them. Acknowledging differences leads to a more inclusive classroom, while ignoring differences in the hopes of “treating them the same” leaves these children feeling unimportant or like an afterthought.
Overall, through this questionnaire, our team was able to understand the skills necessary to properly instruct an equitable STEM curriculum. Comprehending the strengths and weaknesses of instructors was pivotal to the creation of our Student Interaction Guide since we wanted to understand what instructors struggle with and what experienced instructors believe are the most important aspects of teaching (strengths). Furthermore, understanding the ideal mode of professional development was essential because our team wanted to assure that the products we were creating would be digestible to the STEM instructors. We asked about mentorship and advice for new instructors because we wanted to provide advice to new instructors at P.A.Y. Finally, we asked how instructors highlight diversity in the classroom because of the research we found on gender responsive training. We wanted to gain a preliminary understanding of how many instructors teach with diversity in mind and what they define as an inclusive classroom. STEM topics should be taught with all learners in mind. To gain insight on how to do this, we used the experience STEM educators had with including all students. Although we stretched our contacts at the WPI STEM center and MS4SSA, we only received responses from seven educators. To address this main weakness, our team interviewed many of the educators that expressed interest in a follow-up interview and further delved into material that made their responses unique, such as experience teaching STEM at a female boarding school, another rare yet useful experience. These teachers then became consultants to our projects and reviewed many of our deliverables for P.A.Y.
4.2: Preliminary Assessment of Video Training Material

After our group gained feedback from educators that their preferred method of professional development consisted of instructional videos, we began making supplementary videos for the robotics instructors at P.A.Y. Although our group made seven videos, we shared our first draft of our Free Body Diagram (FBD) video, because we believed that it would be easily accessible to viewers of all skill levels. We believed it was necessary to have outsiders evaluate our videos because we wanted to assure that the videos we delivered to P.A.Y. were of the highest quality (Figure 13). We surveyed the viewers to gauge the effectiveness of the video and its content (Appendix E).

![Free Body Diagram Video](image)

**Figure 13: Free Body Diagram Video**

The first question that we asked survey participants was to gauge their prior knowledge of the topic. We wanted to ensure that opinions of the content came from participants with a wide range of prior exposure to the topic, as instructors using this final training content may have significant, little, or no experience with the material. Thirty-seven percent of the 34 participants identified that they were very knowledgeable on FBDs, while 30% stated that they were extremely knowledgeable on the topic. From there, 19% of the viewers expressed that they were moderately knowledgeable of Free Body Diagrams and seven percent each said that they had little to no knowledge of the topic (Figure 14).
The most critical question asked in this survey asked about the effectiveness of the video. We wanted to know the viewer’s honest opinion about the video to drive for improvements in the final submission for P.A.Y. (Figure 15). Overall, 65% of the surveyors rated the video as “above average”, while 23% deemed it as “one of the best” when comparing videos on Free Body Diagrams. From there, 8% of respondents said that it was “average” while 4% stated that it was “below average.” When asked to expand on what could be improved in the video, respondents instructed our team to “add arrows to the forces applied on the block models” and to “draw the free diagrams in the practice problem.” Additionally, one respondent suggested we should “explain why they [FBDs] are important to robot construction.” Through these suggestions, we were able to adjust the technical content to best suit P.A.Y.’s needs and adjust aesthetics to create holistic content. This video was shared through our contacts that we interviewed throughout the term and to friends & family in the WPI community. Although we understand that the results may be biased coming from peers, we told all respondents to take the survey seriously and to assess it critically. Through the feedback from these surveys, we were able to revise the content of the videos to provide clearer explanations.

Figure 14: Viewer’s Prior Knowledge of Free Body Diagrams
The feedback received from this survey allowed for adaptations to our videos to be made. These changes strengthened the outcome of our deliverable and provided us with the feedback needed to produce the best videos we could. We were able to adjust the videos to meet the needs of our sponsors and complete comprehensive videos.

4.3: Most Efficient Method of Curriculum Development

Through interviews and surveys, we gathered the opinions of curriculum development experts on various curriculum development techniques. We developed a weighted decision matrix, Table 2, to determine the curriculum development techniques that would best aid in the rapid development of a high-quality STEM curriculum. Based on our five criteria established in our methods:

- Iterability of the process,
- Availability of tools for the method,
- Usability of the method,
- Effectiveness of the method, as stated by curriculum design professionals and teachers, and
- Recency of the curriculum development method.

Each method’s scores were determined based on the data collected from curriculum design experts and educators. Backward design, SAM, and the design thinking method were seen as the three most efficient models with backward design holding a slight advantage due to its more
widespread success. While no method scored a five in the availability of tools and resources category, a trend began to emerge with backward design, SAM, and the design thinking method having the highest scores. SAM and the design thinking method are newer models and have not had the time to have the same quantity of resources as backward design. There were only two truly iterative methods evaluated, SAM and design thinking, but backward design does have places where iterative processes are recommended. We found that backward design was the easiest method to understand the first time through due to the simplicity of the stages. While SAM, ADDIE, and design thinking were all able to be understood fairly quickly, they still had a steeper learning curve. The recency of each method was evaluated based on when large changes were made to the method by the creators of the method. SAM is the newest method to be released. While backward design and design thinking are still current, they are slightly older reducing their score. Throughout our analysis, Fink’s significant learning consistently scored lower due to it being an outdated technique.

Table 2: Weighted decision matrix comparing curriculum design techniques

<table>
<thead>
<tr>
<th>Criteria</th>
<th>ADDIE</th>
<th>SAM</th>
<th>UbD</th>
<th>DTM</th>
<th>ARCS</th>
<th>FINK'S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iterative</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Available tools</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Usability</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Recent (up to date)</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Raw points</td>
<td>80</td>
<td>46</td>
<td>65</td>
<td>67</td>
<td>64</td>
<td>35</td>
</tr>
<tr>
<td>Percentage</td>
<td>100%</td>
<td>57.50%</td>
<td>81.25%</td>
<td>83.75%</td>
<td>80.00%</td>
<td>43.75%</td>
</tr>
</tbody>
</table>

Based on the decision matrix, we found that backward design (UbD) is the most efficient method of curriculum development for STEM topics. Backward design, as mentioned in the background, starts with the learning objectives, and works backward to what needs to be in the lessons. This method of starting with the learning objectives is what makes it effective for STEM teaching, as it gives instructors confidence that they covered everything the students need to learn.
Backward design was the most common method used by teachers and administrators because of its iterative nature and strong focus on obtaining learning objectives. When asked which curriculum design technique each instructor used the most often, one expert said backward design and then elaborated that it focuses on essential questions and how they should be addressed. When asked to expand on this, this expert noted that backward design makes educators focus on what they want students to learn, leading to a more focused curriculum. Other teachers we surveyed echoed this sentiment saying that it allows for them to remain aligned on the goals of lessons and units. Teachers however did share that due to the goal-focused nature of backward design, once goals have been set it can be hard to justify including extra material that does not directly lead to the students’ understanding of learning objectives.

To counter this, many teachers choose to use the design thinking method as a secondary method to design curricula. While backward design gives the lessons more structure, design thinking allows for the design process to move backward more easily, due to its more iterative nature. Although backward design does have iterative parts, it is mostly within a single stage of the process, so reflection and redevelopment have a much narrower focus. Design thinking, however, actively encourages this throughout the process leading to constant development as the curriculum is progressed through. Therefore, teachers often use it when evaluating and adding new information to the curriculum as their lessons progress.

Another technique that received significant praise in one of our interviews was SAM (successive approximation model). This method is another iterative process that encourages constant development and improvement to curriculum. SAM is one of several agile curriculum design methods that is currently being used by curriculum designers, with a focus on having a working curriculum early in the process and reanalyzing the curriculum as it is implemented.

Overall, the data that we have received suggests using a combination of backward design and a method with a more iterative approach, either design thinking or an agile method like SAM, in unison. This combination allows for a strong goal focused curriculum with the flexibility to address the students' needs the most effectively. Having this combination of techniques will give any curriculum designer the ability to develop a well-rounded curriculum and strong lessons to teach the material.
4.4: Difficulties Administering Robotics Curricula

Through interviews with our sponsor, P.A.Y., we were able to gain knowledge on their current working environment and make recommendations on how to improve it. We also interviewed educators and administration from programs similar to P.A.Y. to gain more insight on the process of curriculum and professional development of STEM instructors.

Through our interviews with P.A.Y., we learned about their current programs and their day-to-day operations. They informed us that they do not have sufficient professional development programs for their instructors, because their current program is mostly instructed by volunteers. However, they do offer their educators the opportunity to go to professional development workshops and programs outside of the facility. But one of the main trends that we saw was the mention of the abundance of resources on professional development already out there that we can integrate into our program. These include already created curricula, guides to student interaction and classroom dynamics, teaching self-help books and online resources.

Another recurring interview topic was how educators create new lessons. Many educators pick their own topics and do their own research to create a curriculum. Due to this feedback, we included a research guide on how to properly do research into specific topics and how to assess what resources are useful. One of the methods of research that we will be suggesting to them is the C.R.A.P. method, as shown in Figure 16. This is one of the methods that we suggested in the Professional Development Resource Guide, meant to give the teachers the proper tool set to vet resources when conducting independent research. This will allow educators to find their own professional development resources if they believe the ones we provide in our program do not work for them. It will also help them with background research for creating their own curriculums in the future and will help with the longevity of P.A.Y.’s program.
Figure 16: C.R.A.P. research method diagram

Mentorship programs amongst educators were a common recommendation throughout our interview process. Many of the educators and administrators that we interviewed said having a new educator observe and learn from existing educators is a great way for them to learn — not only about the teaching, but also about how a classroom operates and how to interact with kids. P.A.Y. already has similar mentorship programs but it is not consistent. Due to this feedback, we integrated mentorship suggestions into our program.

Another overarching trend we found was that instructors should try to find and create ways to make STEM fun, for students and educators alike. Although this is something that is subjective, we integrated ways to make curriculum fun and interactive. A portion of the Student Interaction Guide was dedicated to ways to alter lesson plans and curriculums to make them more enjoyable. It also includes ways to relate the lessons to the students’ current life experiences to make it more personable and encourage interactiveness.

Overall, the responses from these interviews provided the team with the background on the gaps in P.A.Y. ’s STEM education programs that we could help fill. It also provided us with valuable insight into the overarching themes throughout many STEM education programs similar
to P.A.Y. This led to a more detailed and stronger integration of information and suggestions into our program that will make it more effective and have longer lasting effects for P.A.Y.

4.5: Resources Available

P.A.Y. has a wide range of ages to teach, with varying exposure to computers and other underlying skills needed to get the most out of a robotics program at each age level. While developing STEM knowledge through robotics is an important concern for P.A.Y., funding the rest of their wide range of programs is primary. Having the funding for developing the youth of Katutura means working with available resources when possible and minimizing the need for new purchases.

To determine what these critical resources are, lessons can be taken from best practices for curriculum design. One WPI robotics professor said that by picking specific skills that the students should achieve to start with, educators can use backward design to figure out what purchases can lead to the desired educational outcomes. While a 3D printer may be an interesting addition for the classroom, administrators at P.A.Y. told us many of the lower-level students have no practical skills to develop with this tool, and only students with lots of time at a computer and computer-aided design experience will see its full value. This is desirable if the goal is to teach students higher level design, but without this specific goal for most students, this resource will have a reduced impact. In the worst case, it may drain more time out of faculty members’ schedules.

In contrast, resources like computers or kits are much easier to justify purchasing. The 15 computers P.A.Y. has at their disposal ensure that classes (which do not typically exceed 30 students) have at most two students per computer. According to instructors we interviewed, pair-programming and similar collaborative approaches can deepen engagement with lesson content, and in some cases may be preferable to a one computer per child setup. However, one interviewed after-school STEM program emphasized that, especially with courses where an exceedingly large amount of the work is programming or digital design, individual computers for each student make sure they all get full coverage of the knowledge presented. Later assessments can check whether both students in a pair gained the knowledge, but with each student having the ability to try everything on their own and compare with peers, greater understanding can be achieved on the first attempt.
Robot kits with bundled curriculum are a key piece of the robotics education experience. From interviews with schools and extracurricular programs, we learned that some robotics courses opt to use a prebuilt robot to focus only on programming, while others opt to start from basic electrical components, building robots using low-cost microcontrollers. These approaches are not worthless, but resource constraints and the broad range of teaching levels in the robotics program being implemented at P.A.Y. leave kits as one of the best options. The VEX IQ kits provide the most value because of their flexibility, allowing students to design mechanisms of their own, giving students creative expression over what their robot is instead of only what it does.

The price of a kit, like the VEX IQ kits on site at P.A.Y., may be more than that of a prebuilt robot, but the reconfigurability of the parts gives kit materials much more longevity. In contrast, the build-it-from-scratch approach is likely both cheaper and more versatile than a kit. While this combination is attractive, this approach costs a lot of time for the instructors running the program. It is a large undertaking for teachers to select the kit contents, develop lessons to teach general concepts, teach the specifics of the components chosen, and maintain software libraries to make the parts interoperate as indicated through our interview with MS4SSA. Additionally, ensuring continuity of this course between instructors or administrations may be exceedingly difficult due to the large body of work developed by one person. By opting for a kit, like the VEX IQ Superkit, teachers and facilitators can rely on the tooling, training resources, and lesson plans created not only by VEX, but also the plans created by the large community of VEX educators. The trilemma (Figure 17) of finding a low cost, versatile, and easy to use set of classroom resources is a hard constraint problem to solve, with many reasons to prioritize any of two of the three, leaving the other quality to suffer.
Tradeoffs between the three desired qualities in resources for a robotics curriculum are not binary. With each aspect of the resources located on a spectrum, a wider coverage of the listed qualities can be achieved by investing in multiple ecosystems with varied cost, versatility, or ease of use. In concert, these resources can provide the most educational value to students, while mitigating concerns with having weakness in one of the areas.

4.6: Summary of Results

Through surveys and interviews we were able to obtain valuable insight into our research objectives. We were then able to use that information to make significant contributions to our deliverables. We gained more information about which curriculum development plans work best for STEM educators. This insight provided us with more direction to help us decide which method would be utilized in our curriculum development template. We also obtained valuable information about the current working conditions programs similar to P.A.Y. This provided us with more guidance into the proper ways to implement a professional development program that will work for them. Lastly, we achieved a deeper understanding of what resources were most important for our sponsor. This aided us in focusing our research to be able to provide our sponsors with the resources they need to properly implement the professional development program. These modifications to our deliverables allowed us to provide our sponsors with the
most impactful program, such that they can get the most out of our deliverables and to assure that the program is sustainable for many years after the completion of our project.
Chapter 5: Conclusions and Recommendations

The primary goal of our project was to start the development of a scalable training program for STEM educators, beginning in Namibia. To accomplish this, we compiled data from STEM instructors, administrators, curriculum designers, and directors of STEM after-school programs with values similar to that of our sponsor P.A.Y. Through the use of surveys and interviews, we were able to develop training materials to enhance the instructors’ ability to deliver an equitable robotics curriculum through the following deliverables:

- Seven technical videos,
- Student Interaction Guide, and
- Professional Development Resource Documents.

Our team developed seven videos on essential topics to make the instructors at P.A.Y. experts in the topics (Figure 18). Those topics were: Newton's laws, gear ratios, free body diagrams, torque, motors, sensors, and troubleshooting the robot. The videos also included example lessons to implement in the classroom. We also created a Student Interaction Guide that emphasizes best teaching practices for new instructors. Finally, our team developed extensive resources on curriculum development to allow the instructors at P.A.Y. to begin to frame their own lessons on robotics topics.

Figure 18: Tutorial Video on Torque for P.A.Y.
Based on our research and documents created, we recommend that P.A.Y. does the following:

- Include the training videos and *Student Interaction Guide* in trainings for new educators teaching in the robotics program.
- Use backward design and SAM to plan lessons, and to refer to the *Professional Development Resource Guide*.
- Target investments at ensuring there are enough VEX IQ kits, then invest in low-cost microelectronic components to further diversify avenues for instruction.

The lessons we learned in developing a STEM curriculum should not be made exclusive to just P.A.Y. In future work, we believe that this information, specifically the *Student Interaction Guide* and *Professional Development Resource Guide* should be made accessible to instructors of similar programs in the sub-Saharan African region through MS4SSA.

### 5.1: Essential Skills to Instruct an Equitable Robotics Curriculum

Following the completion of our interviews and surveys with STEM educators, our team assessed the best practices of interacting with students and delivering an equitable STEM curriculum. To learn these best practices, we received input from certified STEM instructors and administrators and faculty from after school programs like P.A.Y. We found that STEM instructors’ strengths in delivering a STEM curriculum lie in their enthusiasm, flexibility,
preparedness, and ability to connect activities to the students’ daily lives.

This understanding became integral in the development of the Student Interaction Guide, one of our key deliverables (Figure 19). Our team utilized this finding in the Student Interaction Guide by incorporating details about ways to implement project-based and active learning, which allows the students to create solutions to their own problems (Figure 20). We also emphasized that instructors should be enthusiastic and think ahead in case lessons do not go the way they plan. Through the development of a research guide detailed below, the instructors at P.A.Y. will be able to do proper research on problems that Namibian youth face and how they can be solved utilizing robotics.

**Figure 19: Design of Student Interaction Guide**
Active Learning

Active learning is much like that of project-based learning such that it promotes a deeper understanding of the material being taught by providing it to learners in a non-traditional sense. Active learning is another form of student centered learning. It allows students to be more involved in the classroom. Active learning is a teaching method which engages students in the material through activities that involve classroom discussions, problem solving, writing and reflecting. A study found that active learning can improve examination scores and students’ understanding across all disciplines and in varying class sizes. It is a more passive type of student centered learning compared to project-based learning.

Figure 20: Student Interaction Guide Excerpt

The next major conclusion that our team was able to make was that STEM instructors struggle to allocate time to prepare curricula. To combat this, we organized resources on curriculum design to enable the instructors at P.A.Y. to quickly construct lessons. Through the creation of supplementary videos, our group was able to make the instructors experts in the topics and also provided them with sample lessons that focused on robotics implementations. The teachers also indicated that previously developed lesson plans, instructional videos, and advice from more seasoned educators assisted them the most in delivering a STEM curriculum. Multiple respondents stated that constructing lessons that can be modified for different skill levels and have worksheets and other guiding materials provided the teachers with structure to instruct the lessons. Utilizing this advice, our group supplemented our videos with additional
content about any assumptions that we believed the instructors would already know to assure the material would be accessible to instructors of all skill levels. Finally, our group evaluated responses from instructors on how they can incorporate diversity in their lessons. As Namibia was under apartheid our team wanted to ensure that all students in the classroom felt their voices were heard. Our team provided additional detail on gender responsive training in the Student Interaction Guide and added a list of female STEM role models that the facilitators can use as a basis for their training.

5.2: Curriculum Development using Multiple Methods

Our research showed that the most efficient method of curriculum design is not one single method, but rather a combination of two or more methods. The purpose of this is to create balanced lessons as each design method has different strengths that can counteract each other’s weaknesses. We found that a combination of a method that has more structure to it combined with a method that is more iterative in nature is the strongest combination of methods. We recommend that P.A.Y. uses a combination of backward design and the successive approximation model (SAM). Backward design was consistently held in high regard by the instructors that we interviewed as it has a strong structure designed to ensure that students reach learning objectives while having some flexibility in lesson planning.

Additionally, backward design has the most supporting material available to help instructors use the method including lesson planning sheets, instructional videos, and step by step instructions on how to use it.

SAM is considered an agile curriculum design method, meaning that it is an extremely iterative method. Although it does not have the same amount of structure the curriculum design experts that we spoke to said that it is a very strong way to develop curriculum because it allows for updates to be made at any point in the development. SAM is a slightly newer method and as such it lacks the same amount of supporting material however there is still a wealth of information on the method and how to best use it.

As the staff at P.A.Y. is not familiar with either of these curriculum development techniques, we gave them an organized collection of resources that can be used to apply these methods as they continue to develop their robotics program. These resources include general resources that explain the methods such that the P.A.Y. instructors are familiar and comfortable
with both backward design and SAM as well as materials that will allow them to use these methods to plan new lessons and update older ones. The resources that we are delivering were recommended by WPI curriculum development experts as well as other trusted educators and further vetted by the group to ensure that we were only passing along the best information. These resources will be in both an online and offline version so that the P.A.Y. staff can access it under any circumstances.

5.3: Administering a Successful Robotics Curricula

Through our research we were able to identify the issues that our sponsor and educators face when implementing an effective robotics program. We found that due to a lack of professional development tools and training, the educators were struggling when it came to implementing and expanding upon a robotics curriculum created by a previous IQP group. This program enabled the students to use computer science and engineering principles to design robots.

The main struggle that the educators face is the insufficient amount of professional development resources provided to them. To counter this, we created our Professional Development Resource Guide for the educators to provide them with more support. Another issue they faced was the inability to expand upon the program. This stemmed from a lack of resources available to them as well as a difficulty in researching. We included a research guide for educators in our Professional Development Resource Guide. This guide provides educators with resources and guidance through the process of researching background information for courses. It also includes a guide to how to vet sources so that if a premade course is found and they are interested in including it in their course, they will be able to tell if it is reliable.

We also learned that many educational institutions have mentorship programs for their new educators. P.A.Y. has a similar program, but since most of their educators are volunteers it is hard for them to implement it within the time period working with P.A.Y. Therefore, we suggested that P.A.Y. sets up a collaboration or line of communication with WPI’s MS4SSA. MS4SSA could work with P.A.Y. to set up a mentorship-like program between P.A.Y. instructors and WPI professors or faculty who have experience in fields that the educators need advice in. This will allow P.A.Y. instructors to get advice and help when needed without needing to participate in a time-consuming mentorship program.
We were able to apply our research to add research guides to our *Professional Development Resource Guide*. We were also able to include professional development tools into our informational videos for educators. This information added valuable input for us to create a comprehensive set of resources for P.A.Y.

5.4: Resource Allocation

By conducting interviews with robotics and STEM educators, we found that resource constraints determine much about a robotics program. When determining which aspects to focus on, the three primary constraints: cost, versatility, and simplicity, form a trilemma (Figure 17). In the case of P.A.Y., the trilemma is best resolved by basing choices around a kit ecosystem with a large educator community and existing instructional content for young students, where creating new, engaging content is hardest. For a program catering to such a wide range of skill levels and involving as many students as at P.A.Y., the versatility of a kit allows for many reimaginations of robots, without requiring course staff to check compatibility between parts or design actuators and sensors on their own. While maintaining the low-cost constraint, the options for resources become versatile but hard to use, or simple but inflexible. For P.A.Y.’s current resource allocation, priority should continue to go towards growing their set of VEX IQ kits. While they have twelve of these, more could be used to ensure that kits are shared by at most three students.

To further scale the program, we recommend additional fundraising, to ensure the robotics program does not drain resources from other programs at P.A.Y. With funds allocated from this campaign, the pressure to hold onto the low-cost corner of the trilemma decreases, allowing P.A.Y. to expand from kits like the VEX IQ Superkit to individual components or a more versatile kit, or to entirely pre-built robots. As discussed in the findings, pre-built robots make it easier to teach computer science and programming concepts, without the overhead of assembling a kit (a time-consuming task for younger children). However, after receiving feedback from interviews with P.A.Y. staff, it seems that the next resource target for the robotics program should be individual components. While pre-built robots simplify the process of onboarding new students to the course, and the concepts in it, individual components allow for much greater versatility with the ability to build designs “from scratch”. Teaching for these topics requires greater background knowledge, training, and maintenance than with more widely
used kits, but current instructors at P.A.Y. have the experience necessary to take full advantage of these resources.

In summary, the resources currently at the disposal of the robotics program should go to improving the delivery of the curriculum and program using VEX IQ Superkits, with the target of having no more than 3 students per kit of parts. In order to grow the program without draining other resources at P.A.Y., a fundraising campaign to benefit the robotics program is recommended. In future expansion of the resources used by the program, funds specifically for robotics should be focused on kits or individual components, allowing more versatile robots to be developed. Preliminary recommendations for these parts include ESP32 microcontrollers and Raspberry Pi single-board computers. With these, a new advanced curriculum begins to materialize, with space to design lessons teaching core competencies in electrical engineering, a field that gets left behind when working with more integrated kits, or fully prebuilt robots.

5.5: Future Projects

Throughout our project we have learned a lot about P.A.Y. and their needs. Although we were able to create a professional development program for educators to implement a robotics curriculum at P.A.Y., there are still improvements that can be made to help P.A.Y. create a more robust robotics program. Due to interest from our sponsor, we suggest that a future project for P.A.Y. could be to help them construct a robotics competition centered in Katutura with one of P.A.Y.’s full time staff. Another future project that could be established is to create future lesson plans for P.A.Y. that are adjacent to robotics in different STEM fields. Particularly the instructors were considering going more in depth into the topics of electrical engineering and computer science. A project could be built upon this topic and be focused on delivering P.A.Y. a completed Arduino and Raspberry-Pi centered lesson plan and possibly kits as well. This leads to our last suggestion for future projects finding funding for P.A.Y. through donor mapping. One of the biggest issues P.A.Y. faces is a lack of resources and funding. Creating a project centered on finding ways to combat this issue and provide them with the resources needed to expand and improve for many years will be the most beneficial for the sponsors.
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Appendices

Appendix A: Survey on Curriculum Design Methods

Section 1: Survey Questions

1. The WPI Namibia IQP team 5 invited you to participate in our survey. This survey will aid in the results of a research project which will be completed alongside our sponsors Physically Active Youth and MS4SSA. The project's goal is to create a scalable robotics professional development program for teachers in Namibia. Our team will be surveying educators across the greater Worcester area in order to best prepare the facilitators at Physically Active Youth with the best professional development materials. The survey should take about 10-15 minutes. The results of the research will be published in our final written report. The results of this survey will be completely anonymous and at the end of our report all personal information will be terminated.

This survey is completely voluntary, participants do not need to answer any questions they are not comfortable with or can opt out at any time during the administration of the survey, if they wish.

For more information about this research, about the rights of research participants please contact:

Team 5: Training the Trainers: Developing Robotics Faculty Across Africa: gr-namibiaiqpgroup5@wpi.edu or dpmarsh@wpi.edu

WPI IRB Manager: Ruth McKeogh, Tel, +1 508-831-6699, email: irb@wpi.edu
WPI Human Protection Administrator Gabriel Johnson, Tel +1 508-831-4989 email gjohnson@wpi.edu
a. Agree
2. Name:

3. What age range or grade(s) do you teach?

4. How long have you been teaching?

Backward Design is a model of curriculum development that focuses on in-depth understanding of learning goals. Also known as understanding by design (UbD), UbD consists of three stages, identifying desired results, determining assessment evidence, and planning learning experiences and instruction. UbD is set up to promote long term information retention and skill development by determining how students will display mastery of a topic before creating the instructional material.

5. Have you used the backward design method of curriculum design?
   a. Yes
   b. No
   c. I have never heard of the backward design method

6. Is backward design your preferred method of curriculum development?
   a. Yes
   b. No

7. How often do you use backward design?
   a. Every time I develop new or update existing curriculum
   b. When developing new curriculum
c. When updating existing curriculum
d. Occasionally if I feel it is best suited to the curriculum I am developing
e. When the other people I am working with use it
f. Never

8. Why do you use the ADDIE method at the frequency you do? (Open ended)

The design thinking model of curriculum design focuses on understanding a learners needs and developing specific solutions to address those needs. This model is composed of five stages: empathize, define, ideate, prototype, and test. The first stage, empathize, requires the curriculum developer to “gain an empathic understanding of the problem [they] are trying to solve” (Friis Dam & Siang, 2021). The empathize stage is a research phase when as much information on the problem should be gathered. The second stage, define, is where the core problems are identified to be solved. Throughout this method, it is important to frame information in a human centric manner as to make the students the most important people in the curriculum.

9. Have you used the design thinking model of curriculum design?
   a. Yes
   b. No
   c. I have never heard of the design thinking model

10. Is design thinking your preferred method of curriculum development?
    a. Yes
    b. No

11. How often do you use design thinking?
    a. Every time I develop new or update existing curriculum
    b. When developing new curriculum
c. When updating existing curriculum
d. Occasionally if I feel it is best suited to the curriculum I am developing
e. When the other people I am working with use it
f. Never

12. Why do you use design thinking at the frequency you do? (Open ended)

ARCS is an acronym for attention, relevance, confidence, and satisfaction and focuses on maintaining learner motivation throughout instruction. Material used needs to gain the learners attention, through real world examples, participation, and inquiry as well as through variable teaching methods. The relevance of the information being presented needs to be made apparent using concrete examples.

13. Have you used the ARCS method of curriculum design?
   a. Yes
   b. No
   c. I have never heard of the ARCS method

14. Is ARCS your preferred method of curriculum development?
   a. Yes
   b. No

15. How often do you use ARCS?
   a. Every time I develop new or update existing curriculum
   b. When developing new curriculum
c. When updating existing curriculum
d. Occasionally if I feel it is best suited to the curriculum I am developing
e. When the other people I am working with use it
f. Never

16. Why do you use ARCS at the frequency you do? (Open ended)

The most common curriculum development methodology is the ADDIE method. ADDIE is an acronym, standing for analysis, design, development, implementation, and evaluation, with each letter standing for a stage of the design process.

17. Have you used the ADDIE or SAM methods of curriculum design?
   a. Yes
   b. No
c. I have never heard of the ADDIE or SAM methods

18. Is the ADDIE method your preferred method of curriculum development?
   a. Yes
   b. No

19. How often do you use the ADDIE method?
   a. Every time I develop new or update existing curriculum
   b. When developing new curriculum
   c. When updating existing curriculum
d. Occasionally if I feel it is best suited to the curriculum I am developing
e. When the other people I am working with use it
f. Never

20. Why do you use the ADDIE method at the frequency you do? (Open ended)
Fink’s significant learning model is “... rooted in the belief that, for learning to occur, there must be a change in the learner” (Burnham, 2020). There are six categories of learning, foundational knowledge, application, integration, human dimension, caring, and learning how to learn. While Fink’s model doesn’t outline a specific strategy for building a curriculum, it states that each of these types of learning is required for a full understanding of a subject and that curriculum should be built to include all six categories.

21. Have you used the Fink’s significant learning method of curriculum design?
   a. Yes
   b. No
   c. I have never heard of the Fink’s significant learning method

22. Is Fink’s significant learning method your preferred method of curriculum development?
   a. Yes
   b. No

23. How often do you use Fink’s significant learning method?
   a. Every time I develop new or update existing curriculum
   b. When developing new curriculum
   c. When updating existing curriculum
   d. Occasionally if I feel it is best suited to the curriculum I am developing
   e. When the other people I am working with use it
   f. Never
24. Why do you use Fink’s significant learning method at the frequency you do? (Open ended)

25. Are there other methods of curriculum design that you use? If yes, please list.
Section 2: Survey Results

1. What age range or grade(s) do you teach?
   - Respondent 1: Grades 6-8
   - Respondent 2: Grades 7-12
   - Respondent 3: For this year, I teach 8th grade. But I usually have grades 6-8.
   - Respondent 4: Eighth grade and college
   - Respondent 5: 8th grade
   - Respondent 6: Grades 9-12
   - Respondent 7: PK16

2. How long have you been teaching?
   - Respondent 1: 18 years
   - Respondent 2: 5 years
   - Respondent 3: 13 years
   - Respondent 4: 25 years
   - Respondent 5: 11 years in the classroom
   - Respondent 6: 14 years
   - Respondent 7: 30+ years
Backward Design is a model of curriculum development that focuses on in-depth understanding of learning goals. Also known as understanding by design (UbD), UbD consists of three stages, identifying desired results, determining assessment evidence, and planning learning experiences and instruction. UbD is set up to promote long term information retention and skill development by determining how students will display mastery of a topic before creating the instructional material.

3. Have you used the backward design method of curriculum design?
   - Respondent 1: Yes
   - Respondent 2: Yes
   - Respondent 3: Yes
   - Respondent 4: Yes
   - Respondent 5: Yes
   - Respondent 6: Yes
   - Respondent 7: Yes

4. Is backward design your preferred method of curriculum development?
   - Respondent 1: No
   - Respondent 2: Yes
   - Respondent 3: Yes
   - Respondent 4: No
   - Respondent 5: Yes
   - Respondent 6: Yes
   - Respondent 7: Yes
5. How often do you use backward design?
   ○ Respondent 1: Occasionally if I feel it is best suited to the curriculum I am developing
   ○ Respondent 2: When developing new curriculum
   ○ Respondent 3: When developing new curriculum
   ○ Respondent 4: Occasionally if I feel it is best suited to the curriculum I am developing
   ○ Respondent 5: Every time I develop new or update existing curriculum
   ○ Respondent 6: When developing new curriculum
   ○ Respondent 7: Every time I develop new or update existing curriculum

6. Why do you use the Backward Design method at the frequency you do? (Open ended)
   ○ Respondent 1: Develop lessons and activities based upon MCAS results
   ○ Respondent 2: It is measurable and goal focused
   ○ Respondent 3: it works
   ○ Respondent 4: Only sometimes are the results predetermined. Other times, the students' interests must be measured iteratively and expectations changed. Backwards measuring may be considered a tool for standards-oriented industrial education.
   ○ Respondent 5: To save on planning time and use student time with focus and purpose
   ○ Respondent 6: After 14 years I have well developed programs of instruction, that are successful.
   ○ Respondent 7: Backward design complements the standards based instructional models I have used.
The design thinking model of curriculum design focuses on understanding a learner's needs and developing specific solutions to address those needs. This model is composed of five stages: empathize, define, ideate, prototype, and test. The first stage, empathize, requires the curriculum developer to “gain an empathic understanding of the problem [they] are trying to solve” (Friis Dam & Siang, 2021). The empathize stage is a research phase when as much information on the problem should be gathered. The second stage, define, is where the core problems are identified to be solved. Throughout this method, it is important to frame information in a human-centric manner as to make the students the most important people in the curriculum.

7. Have you used the design thinking model of curriculum design?
   - Respondent 1: I have never heard of the design thinking model
   - Respondent 2: Yes
   - Respondent 3: Yes
   - Respondent 4: Yes
   - Respondent 5: Yes
   - Respondent 6: I have never heard of the design thinking model
   - Respondent 7: Did not respond

8. Is design thinking your preferred method of curriculum development?
   - Respondent 1: No
   - Respondent 2: No
   - Respondent 3: Yes
   - Respondent 4: Yes
   - Respondent 5: No
   - Respondent 6: No
   - Respondent 7: Did not respond
9. How often do you use design thinking?
   ○ Respondent 1: Never
   ○ Respondent 2: Occasionally if I feel it is the best suited to the curriculum I am developing
   ○ Respondent 3: Every time I develop new or update existing curriculum
   ○ Respondent 4: When developing new curriculum
   ○ Respondent 5: Occasionally if I feel it is the best suited to the curriculum I am developing
   ○ Respondent 6: Never
   ○ Respondent 7: Did not respond

10. Why do you use design thinking at the frequency you do? (Open ended)
   ○ Respondent 1: Did not know existed
   ○ Respondent 2: It really depends on what the goal is for the lesson(s)
   ○ Respondent 3: I like that it is a human centered approach, and I tailor the curriculum to the students I have. Taking into account their learning styles, interest, their backgrounds, etc.
   ○ Respondent 4: Did not respond
   ○ Respondent 5: The students are relying on me to cover more material than what this approach allows. This also creates a reoccurring problem of inefficient resources to support students.
   ○ Respondent 6: Not heard of it
   ○ Respondent 7: Did not respond
ARCS is an acronym for attention, relevance, confidence, and satisfaction and focuses on maintaining learner motivation throughout instruction. Material used needs to gain the learners attention, through real world examples, participation, and inquiry as well as through variable teaching methods. The relevance of the information being presented needs to be made apparent using concrete examples.

<table>
<thead>
<tr>
<th>Attention</th>
<th>Relevance</th>
<th>Confidence</th>
<th>Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceptual arousal</td>
<td>Goal orientation</td>
<td>Learning requirements</td>
<td>Intrinsic reinforcement</td>
</tr>
<tr>
<td>Provide novelty and surprise</td>
<td>Present objectives and useful purpose of instruction and specific methods for successful achievement</td>
<td>Inform students about learning and performance requirements and assessment criteria</td>
<td>Encourage and support intrinsic enjoyment of the learning experience</td>
</tr>
<tr>
<td>Inquiry arousal</td>
<td>Motivation matching</td>
<td>Successful opportunities</td>
<td>Extrinsic rewards</td>
</tr>
<tr>
<td>Stimulate curiosity by posing questions or problems to solve</td>
<td>Match objectives to student needs and motives</td>
<td>Provide challenging and meaningful opportunities for successful learning</td>
<td>Provide positive reinforcement and motivational feedback</td>
</tr>
<tr>
<td>Variability</td>
<td>Familiarity</td>
<td>Personal responsibility</td>
<td>Equity</td>
</tr>
<tr>
<td>Incorporate a range of methods and media to meet students' varying needs</td>
<td>Present content in ways that are understandable and that related to the learners' experiences and values</td>
<td>Link learning success to students' personal effort and ability</td>
<td>Maintain consistent standards and consequences for success</td>
</tr>
</tbody>
</table>

11. Have you used the ARCS method of curriculum design?
   ○ Respondent 1: I have never heard of the ARCS method
   ○ Respondent 2: I have never heard of the ARCS method
   ○ Respondent 3: I have never heard of the ARCS method
   ○ Respondent 4: I have never heard of the ARCS method
   ○ Respondent 5: I have never heard of the ARCS method
   ○ Respondent 6: I have never heard of the ARCS method
   ○ Respondent 7: Did not respond

12. Is ARCS your preferred method of curriculum development?
   ○ Respondent 1: No
   ○ Respondent 2: No
   ○ Respondent 3: No
   ○ Respondent 4: No
   ○ Respondent 5: No
   ○ Respondent 6: No
   ○ Respondent 7: Did not respond
13. How often do you use ARCS?
   ○ Respondent 1: Never
   ○ Respondent 2: Never
   ○ Respondent 3: Never
   ○ Respondent 4: Never
   ○ Respondent 5: Never
   ○ Respondent 6: Did not respond
   ○ Respondent 7: Did not respond

14. Why do you use ARCS at the frequency you do? (Open ended)
   ○ Respondent 1: Never learned about it
   ○ Respondent 2: This looks interesting - like a rubric I just haven't been exposed to it recently but I really like it and follow up with it
   ○ Respondent 3: Never heard of it
   ○ Respondent 4: This is close to my college labs curriculum method, but I'd never seen it written.
   ○ Respondent 5: Never heard of it, seems less practical use of time to unpack, I might already do most of this
   ○ Respondent 6: Did not respond
   ○ Respondent 7: Did not respond
The most common curriculum development methodology is the ADDIE method. ADDIE is an acronym, standing for analysis, design, development, implementation, and evaluation, with each letter standing for a stage of the design process.

15. Have you used the ADDIE or SAM methods of curriculum design?
   ○ Respondent 1: I have never heard of the ADDIE or SAM methods
   ○ Respondent 2: I have never heard of the ADDIE or SAM methods
   ○ Respondent 3: I have never heard of the ADDIE or SAM methods
   ○ Respondent 4: I have never heard of the ADDIE or SAM methods
   ○ Respondent 5: No
   ○ Respondent 6: Did not respond
   ○ Respondent 7: Did not respond

16. Is the ADDIE method your preferred method of curriculum development?
   ○ Respondent 1: No
   ○ Respondent 2: No
   ○ Respondent 3: No
   ○ Respondent 4: No
   ○ Respondent 5: No
   ○ Respondent 6: Did not respond
   ○ Respondent 7: Did not respond

17. How often do you use the ADDIE method?
   ○ Respondent 1: Never
   ○ Respondent 2: Never
   ○ Respondent 3: Never
   ○ Respondent 4: Never
   ○ Respondent 5: Never
18. Why do you use the ADDIE method at the frequency you do? (Open ended)

- Respondent 1: Did not know existed
- Respondent 2: This looks interesting - I did teacher training awhile ago so I am realizing I am missing the newer techniques
- Respondent 3: I have never used it
- Respondent 4: Again, many elements of what I do as a curriculum consultant, but I'd never heard of ADDIE.
- Respondent 5: Seems like a school structure and culture need to be in place for this before doing in a classroom.
- Respondent 6: Did not respond
- Respondent 7: Did not respond
Fink’s significant learning model is “... rooted in the belief that, for learning to occur, there must be a change in the learner” (Burnham, 2020). There are six categories of learning, foundational knowledge, application, integration, human dimension, caring, and learning how to learn. While Fink’s model doesn’t outline a specific strategy for building a curriculum, it states that each of these types of learning is required for a full understanding of a subject and that curriculum should be built to include all six categories.

19. Have you used the Fink’s significant learning method of curriculum design?
   ○ Respondent 1: I have never heard of Fink’s significant learning method
   ○ Respondent 2: Yes
   ○ Respondent 3: I have never heard of Fink’s significant learning method
   ○ Respondent 4: I have never heard of Fink’s significant learning method
   ○ Respondent 5: I have never heard of Fink’s significant learning method
   ○ Respondent 6: Did not respond
   ○ Respondent 7: Did not respond

20. Is Fink’s significant learning method your preferred method of curriculum development?
   ○ Respondent 1: No
   ○ Respondent 2: No
   ○ Respondent 3: No
   ○ Respondent 4: No
   ○ Respondent 5: No
   ○ Respondent 6: Did not respond
21. How often do you use Fink’s significant learning method?

- Respondent 1: Never
- Respondent 2: When the other people I am working with use it
- Respondent 3: Never
- Respondent 4: When updating existing curriculum
- Respondent 5: Never
- Respondent 6: Did not respond
- Respondent 7: Did not respond

22. Why do you use Fink’s significant learning method at the frequency you do? (Open ended)

- Respondent 1: Never heard of this
- Respondent 2: I was taught one way to curriculum plan
- Respondent 3: I have never used it
- Respondent 4: Yet again, I'd never heard of Fink's but I combine the same elements iteratively quite frequently in curriculum design.
- Respondent 5: Not familiar with this
- Respondent 6: Did not respond
- Respondent 7: Did not respond

23. Are there other methods of curriculum design that you use? If Yes, please list.

- Respondent 1: Have learning gap or standard that needs reinforcing or instruction and find activities that are age appropriate and help make real world connections
- Respondent 2: Did not respond
- Respondent 3: Did not respond
- Respondent 4: 25 years after my advanced studies in curriculum, I don't stick to any one named method. I pull resources from books, consider the students, measure the students, adapt resources, ask the student to take some charge of the curriculum, etc. This survey has been a little like asking what we like to eat, wheat corn or rice? We answer whatever is in this bowl with mangoes.
○ Respondent 5: Applying UBD to state standards: the standard dictates what needs to be done to meet the expectation. I choose the most appropriate mode for my students to meet the expectation. The method of CD is the logical best fit.
○ Respondent 6: Did not respond
○ Respondent 7: Did not respond
Appendix B: Surveying STEM Educators in the Worcester Area

Section 1: Survey Questions

1. What is your name?

2. What is your email?
   a. Email (Open Answer)
   b. I would not like to receive any follow up information

3. Would you be interested in a follow up interview with us?
   a. Yes
   b. No

4. What is your age?
   a. (Open Answer)

5. What is your gender?
   a. Male
   b. Female
   c. Non-Binary
   d. (Open Answer)

6. Which location would best describe where you teach?
   a. Town
   b. City
   c. Major City/Capitol
   d. (Open Answer)

7. What age range do you instruct? [Allow multiple boxes to be checked]
   a. 4-6
   b. 6-8
   c. 8-10
   d. 10-12
   e. 12-14
8. How many years have you been instructing STEM Topics:
   a. 0-1 years
   b. 1-3 years
   c. 3-5 years
   d. 5-10 years
   e. 10-20 years
   f. 20-30 years
   g. 30 years +
9. What do you believe are your greatest strengths in instructing STEM topics?
   a. (Open Answer)
10. What do you believe are your greatest weaknesses in instructing STEM topics?
    b. (Open Answer)
11. What professional development tools have you used to supplement your ability to teach STEM topics?
    a. Instructional Videos from Universities
    b. Previously developed lesson plans from older teachers
    c. Professional Development Resources given by administration
    d. Other (Open Answer)
12. What professional development resources do you believe are the best at communicating best methods for teaching a STEM curriculum
    a. (Open Answer)
13. If you could give one piece of advice to a new teacher what would you say to help them be more effective in delivering a STEM education (Gibbs, 2019).
    a. (Open Answer)
14. Have you ever had a student-teacher shadow you?
    a. If yes, what did you find was the most effective way to teach them. Moreover what would you say is the best way to be a mentor and provide constructive criticism to educators? (Gibbs, 2019)
b. No

15. In what ways if any, do you highlight diversity in STEM topics?
   a. (Open Answer)

16. Have you ever taught specific to gender, or participated in gender-awareness training through the use of role models for girls in STEM fields
   a. Yes
   b. No
Section 2: Survey Results

1. The WPI Namibia IQP team 5 invited you to participate in our survey. This survey will aid in the results of a research project which will be completed alongside our sponsors Physically Active Youth and MS4SSA. The project's goal is to create a scalable robotics professional development program for teachers in Namibia. Our team will be surveying educators across the greater Worcester area in order to best prepare the facilitators at Physically Active Youth with the best professional development materials. The survey should take about 10-15 minutes. The results of the research will be published in our final written report. The results of this survey will be completely anonymous and at the end of our report all personal information will be terminated.

This survey is completely voluntary, participants do not need to answer any questions they are not comfortable with or can opt out at any time during the administration of the survey, if they wish,

For more information about this research, about the rights of research participants please contact:

Team 5: Training the Trainers: Developing Robotics Faculty Across Africa:

gr-namibiaiqpgroup5@wpi.edu or dpmarsh@wpi.edu

WPI IRB Manager: Ruth McKeogh, Tel, +1 508-831-6699,
email: irb@wpi.edu

WPI Human Protection Administrator Gabriel Johnson, Tel +1 508-831-4989
email gjohnson@wpi.edu

Do you agree:

Survey Respondent 1: Agree
Survey Respondent 2: Agree
Survey Respondent 3: Agree
Survey Respondent 4: Agree
Survey Respondent 5: Agree
Survey Respondent 6: Agree
Survey Respondent 7: Agree

1. Would you be interested in a follow up interview with us?

· Survey Respondent 1: Yes
Survey Respondent 2: Yes
Survey Respondent 3: Yes
Survey Respondent 4: Yes
Survey Respondent 5: Yes
Survey Respondent 6: Yes
Survey Respondent 7: No

2. What is your age?
Survey Respondent 1: 59
Survey Respondent 2: 61
Survey Respondent 3: 39
Survey Respondent 4: 41
Survey Respondent 5: 49
Survey Respondent 6: 68
Survey Respondent 7: 45

3. What is your gender?
Survey Respondent 1: Female
Survey Respondent 2: Male
Survey Respondent 3: Male
Survey Respondent 4: Female
Survey Respondent 5: Female
Survey Respondent 6: Female
Survey Respondent 7: Female

6. Which location would best describe where you teach?
Survey Respondent 1: Town
Survey Respondent 2: Town
7. What age range do you instruct? [Allow multiple boxes to be checked]

- Survey Respondent 1: 10-16 years old
- Survey Respondent 2: 4-6 years old, 6-8 years old, 8-10 years old, 10-12 years old, 12-14 years old, 14-16 years old, 16-18 years old, College/university
- Survey Respondent 3: 10-12 years old, 12-14 years old
- Survey Respondent 4: 10-16 years old
- Survey Respondent 5: 10-18 years old
- Survey Respondent 6: 10-18 years old
- Survey Respondent 7: 12-18 years old

8. How many years have you been instructing STEM Topics:

- Survey Respondent 1: 5-10 years
- Survey Respondent 2: 20-30 years
- Survey Respondent 3: 10-20 years
- Survey Respondent 4: 10-20 years
- Survey Respondent 5: 10-20 years
- Survey Respondent 6: 30 years +
- Survey Respondent 7: 3-5 years

9. What do you believe are your greatest strengths in instructing STEM topics?
• Survey Respondent 1: Love for the subject matter and enthusiasm

• Survey Respondent 2: STEM topics can be easily connected with the day to day work/activities of people. This provides greater instructional access to prior knowledge and sets a foundation for quality scaffolding of instruction

• Survey Respondent 3: anticipating the way students will perceive, understand, and question the materials we see

• Survey Respondent 4: I love math and CS and bring my passion! I also try to find fun and creative ways to allow students to engage with the material

• Survey Respondent 5: being flexible...sometimes you have to change the project to improve it, and/or tailor it for your current students

• Survey Respondent 6: Making fun, but educational opportunities on a cheap budget

• Survey Respondent 7: enthusiasm

10. What do you believe are your greatest weaknesses in instructing STEM topics?

• Survey Respondent 1: Lack of engineering degree

• Survey Respondent 2: The disconnect some see between STEM and the humanities. Building bridges between STEM and humanities strengthens both.

• Survey Respondent 3: coordinating physical materials for structured investigations

• Survey Respondent 4: Time for planning

• Survey Respondent 5: getting student work graded quickly and returned to students so they can make improvements to their work

• Survey Respondent 6: Time availability in school

• Survey Respondent 7: lack of supplies too many students

11. What professional development tools have you used to supplement your ability to teach STEM topics?

• Survey Respondent 1: Hands on instruction and ability to try it out yourself first

• Survey Respondent 2: All of the above and more – differentiation of instruction meets the greatest number of learners

• Survey Respondent 3: Previously development resources given by administration

• Survey Respondent 4: all of the above
· Survey Respondent 5: Previously developed lesson plans

· Survey Respondent 6: NSTA conferences

· Survey Respondent 7: Previously developed lesson plans

12. What professional development resources do you believe are the best at communicating best methods for teaching a STEM curriculum

· Survey Respondent 1: Hands on instructions and ability to try it out yourself first

· Survey Respondent 2: Any PD resource that looks at STEM as being interdisciplinary

· Survey Respondent 3: lesson resources from other seasoned teachers who have taught recently (within the last 3 years)

· Survey Respondent 4: Hands on learning with other teachers - time to tinker and play

· Survey Respondent 5: The best resources are other STEM teachers! Talking to other teachers you can get ideas for new projects, ways to improve current projects, or ideas to improve the rigor and make the projects more authentic

· Survey Respondent 6: PD that allows the participant to act the role of the student. Be active and inquisitive.

· Survey Respondent 7: lessons that can modified that have the worksheets, materials, power points, descriptions

13. If you could give one piece of advice to a new teacher what would you say to help them be more effective in delivering a STEM education (Gibbs, 2019).

· Survey Respondent 1: Have your lessons and or instruction make connections to something the kids relate to and have practical applications for them

· Survey Respondent 2: Come to the STEM table with a framework in mind like “Nature of Science” with the 7-8 key concepts hold greater meaning.

· Survey Respondent 3: Be clear with students, no sarcasm, no figurative language unless presented as such, no trick questions, and check in with them frequently to ask if they need anything that is not already offered. Be honest, build trust, the rest will follow.

· Survey Respondent 4: Make sure you try the problems/activities yourself. Give yourself time to grapple with the material and make mistakes.

· Survey Respondent 5: Be flexible...teach to the students you have in front of you. This might mean you have to change up your methods from year to year.

· Survey Respondent 6: Let the students have a say in the direction they take a project.
14. Have you ever had a student-teacher shadow you?
   a. If yes, what did you find was the most effective way to teach them. Moreover what would you say is the best way to be a mentor and provide constructive criticism to educators? (Gibbs, 2019)
   b. No

Survey Respondent 1: Yes: I Let the student get right into the teaching right away. Wait until the lesson over and discuss results

Survey Respondent 2: Student Teachers and interns learn best when provided the opportunity to jump right into their teaching with a mentor who can coach along side that new to teaching teacher. The key is to have a lead teacher with a clear understanding of both pedagogy and andragogy. In other words the mentor should come to the table with a strong sense of how various age children learn and also have a great sense of adult learning theory so as to be in a position to effectively support a person new to teaching. The mentor must be a great coach!

Survey Respondent 3: No

Survey Respondent 4: No

Survey Respondent 5: No

Survey Respondent 6: Yes

Survey Respondent 7: No

15. In what ways if any, do you highlight diversity in STEM topics?

Survey Respondent 1: Encourage all abilities of students to participate

Survey Respondent 2: Diversity of learning styles is critical to helping student gain a strong understanding of STEM topics. Bringing together a group of students with different backgrounds adds to the quality of STEM conversations in the classroom

Survey Respondent 3: I will reject a video if it does not show diversity. If I must use a resource and it is not diverse I will point out that it is inaccurate of the real world and apologize for not finding anything better.
Survey Respondent 4: I used Mobile CSP, a curriculum designed to integrate lessons regarding different STEM careers and types of contributors to the development of CS.

Survey Respondent 5: Use design thinking...which is a human centered approach to problem solving. This gives students a chance to focus on improving lives for others with their designs.

Survey Respondent 6: By bringing in resources from all over the world for readings.

Survey Respondent 7: try to use a variety of backgrounds so can get different views. More views better problem solving.

16. Have you ever taught specific to gender, or participated in gender-awareness training through the use of role models for girls in STEM fields
   · Survey Respondent 1: Yes: WPI Camp Counselor
   · Survey Respondent 2: Yes: Eureka Girls Inc. Teen Center - Supported
   · Survey Respondent 3: Maybe
   · Survey Respondent 4: I am a women and have received the gender diversity recognition from college board
   · Survey Respondent 5: No
   · Survey Respondent 6: Smith College had a program about girls and STEM. I treat girls like boys – everyone is equal
   · Survey Respondent 7: No

Questions that disclosed personal information were taken out of the appendix.
Appendix C: Interview Questions for Instructors and Administrators in Namibia

For Educators:

1. What age range do you teach?
2. What is your biggest struggle besides resources within the classroom?
3. What teaching methods do you use most often?
4. How do you measure a student's understanding of the material?
5. What do you want to see in a teaching manual or professional development program?
6. How do you prepare a lesson for students?
7. How do your teaching goals translate to learning outcomes for a professional development program?
8. What professional development techniques have helped you in the past? What was good about them? What could be improved upon?
9. What can we do to make learning the material practical within your time frame?
10. What skill do you think you need to improve on most when it comes to interacting with students?
11. Are different methods being used to teach the robotics curriculum within P.A.Y. between faculty? Why or why not?
12. What small resources, either physical or emotional do you think would improve your teaching methods?
13. What does your current professional development look like?

For Administrators:

1. What is the goal setting process in your school?
2. How are your school’s goals related to the district goals and the goals for continuous academic improvement?
3. What opportunities have you used to engage your teachers in collaboration relative to vision, mission, and strategic goals?
4. What are the barriers to your goals and what can you/we do to minimize them?
5. How do you articulate the vision and mission of your school so that it is understood?
6. How have you used the data from all local and state data to inform your decision making and goal setting?

7. How do teachers in your school have a voice in decisions?

8. How are your teachers involved in the planning and assessment of your school’s goals?

9. What opportunities have you used to engage your teachers in building a collaborative and empowering work environment?

10. What is your greatest barrier to increased student achievement and what efforts are you making to address the barriers?

11. How are you helping your teachers to be experts in the curriculum and how can we improve upon this?

12. What benchmarks do you have in place to encourage continuous academic improvement?

13. What kind of training do you already have in place for novice teachers who are hired to work in your building?

14. How does your professional development compare to other school in the area?
Appendix D: Timeline for project

<table>
<thead>
<tr>
<th>Activity</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Week 7</th>
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</thead>
<tbody>
<tr>
<td>Share Questionnaires with Worcester STEM educators</td>
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<tr>
<td>Conduct interviews with Physically Active Youth about resources and existing curricula</td>
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<tr>
<td>Analyzing results of questionnaires and interviews with PAY and Worcester Instructors</td>
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<tr>
<td>Create curriculum development template for PAY instructors</td>
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<td>Develop video consent with VEX IQ Superkits to enhance understanding of instructors</td>
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<td>Design updated facilitator's manual with best teaching practices</td>
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<tr>
<td>Produce final proposal and presentation material</td>
<td>revise methodology</td>
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<td></td>
<td>submit results again</td>
<td></td>
<td>Final draft of full report</td>
</tr>
</tbody>
</table>
Appendix E: Results of Preliminary Assessment of Videos

Prior to watching the video, how would you describe your knowledge on the topic of Free Body Diagrams

![Bar Chart showing the level of knowledge on Free Body Diagrams before watching the video. The chart shows a high percentage of respondents describing their knowledge as 'Extremely knowledgeable' and 'Very knowledgeable'.]
If you have experience working with Free Body Diagrams, please assess how the video describes them (if no prior knowledge please skip this question).
Do you believe there is any additional information on Free Body Diagrams that would aid in the understanding of the material? If so, please describe this below?
Very clear how the diagram helps sort out the forces. Less clear how to use the end results of all of the calculations.

I think students need to see a video of the robot actually moving before drawing any free body diagrams.

Where do forces come from?

Add arrows to the forces applied on the block models, also drawing the free diagrams and explaining them in the practice problem could be more helpful.

For how they relate to robots, maybe explain why they are important to robot construction, the section of the robot driving up the ramp was cool, but why do math when you can just observe what it does?

There needs to be visual examples with the robot in split screen with the diagram.

I am not sure if this is the goal, but taking a minute at the beginning to say how a free body diagram box is a simplistic way to represent an object

Depending on your target audience, Friction could use a little more explaining!

Sometimes the arrow tails aren't at the center of the diagram, which I feel is a point of confusion.
Appendix F: Student Interaction Guide

This document is included beginning on the next page.
DEVELOPED FOR PHYSICALLY ACTIVE YOUTH

STUDENT INTERACTION GUIDE

Designing & Delivering
STEM Lessons with
Learners in Mind

JOHN BENOIT, ELIZABETH DIRUZZA,
ANDREW FISHER, & DANIEL MARSH
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Introduction

This guide contains suggestions on how to improve a student’s learning experience. The methods we discussed range from effectively managing the classroom to properly assessing each student’s knowledge. In each of the different sections, we discussed specific skills and methods that will help a teacher continue to improve their presence in the classroom. We also share information about the implementation and usage of each skill or method into daily lessons.

This guide also contains an in depth discussion on gender and diversity and their place in the classroom. Through these sections, we state how instructors can promote diversity and inclusivity in their teaching methods to cater to everyone in the classroom. When instructors foster a diverse and inclusive learning environment, the students have the space to excel in technical fields. In this document we provide suggestions found through research and discussions with STEM educators and after school administrators.
Classroom Management

Through our research we found nine different strategies that teachers consistently sighted as helping improve their classroom management. Effectively utilizing these skills will allow instructors to have more control of the classroom giving them more instruction time. The skills can be split into three separate categories: instructor-student relationships, time management, and enforcing rules.

The first set of skills are all designed to help instructors build a strong relationship with their students. A strong relationship with a student is more than the student simply liking the instructor, the student should respect the instructor and trust that they have their best interests in mind. There are many different methods for developing a strong relationship with each student and not every student is going to respond the same way to the same thing.

One recommendation to build a strong relationship with students is to greet them at the door at the start of a lesson. This establishes a positive tone for the rest of the lesson and can “boost academic engagement by 20 percentage points while reducing disruptive behavior by 9 percentage points”. This slight change can add over four and a half minutes of instructional time to a one hour lesson. Another way an instructor can connect with the students more is by scheduling one-on-one meetings to get to know them better. Through these one-on-one meetings instructors can begin to understand the students’ likes and dislikes, the things they enjoy and the ways they learn best. If the student feels that the instructor is actively trying to support them and know them, they are more likely to respond.

more positively to directions and pay attention in class. Another method for instructors to foster strong relationships with their students is to acknowledge good behavior\(^2\). By highlighting the right thing to do, students are more likely to follow this course of action. If instructors go out of their way to recognize and value the skills and experiences the students bring to the classroom, the students often gain ownership in their work. Once students have ownership in their projects, they can build passion in the material and this could enhance their understanding of the material. Having a strong relationship with students allows for instructors to have more control over what happens in the classroom as students are more likely to follow instructions.

Managing time is another important skill for instructors to develop. Being able to control the amount of time spent on a particular topic or in the transitions between topics or activities allows instructors to spend more time teaching and less time trying to get the class focused. The first skill that will help any instructor manage time is to be prepared. Instructors need to be prepared for the lesson as well as to face any problems that may arise. Having a plan to redirect attention to the material when the students get distracted will allow class to resume more quickly as there are already steps in place to address the situation\(^3\).

Another important time management skill is to have planned transitions from one activity to the next. This transition time is when students are the most likely to get distracted.


and derail a strong lesson plan. Having a plan on how to keep things moving quickly between activities gives students less of an opportunity to get distracted as they are already engaged with the next topic\(^4\). Also, planned transitions allow for instructors to develop a routine so that students know what to expect as the lesson progresses. By successfully managing time, instructors are able to deliver more of the material that is important and spend less time trying to get back on topic.

Developing rules is a critical part of managing a classroom. To assure the success of these rules, they need to be clearly established. One way an instructor can get the students to follow the rules is to get them involved in the rulemaking process. At the beginning of your program, allocate about an hour to establish the rules with the students, as this will give them ownership in what happens in the classroom. If the rules are not clearly established students may not understand expectations and are more likely to become distracted or misbehave\(^3\). When students do start to misbehave, addressing the issue before it becomes a big deal as making corrections to small issues is much easier than trying to fix something when the entire lesson has been derailed\(^5\). When rules have been established it is also important to enforce them fairly and consistently not showing favoritism or changing how rules are enforced\(^1\).

---


Having effective classroom management skills will improve the success of lessons and make classes flow smoothly and efficiently. If an instructor can master all three of the parts of effective classroom management they will be able to become very successful.
PAY

PROJECT BASED & ACTIVE LEARNING

STUDENT INTERACTION GUIDE
Project-Based & Active Learning

Through our research and interviews with the WPI STEM Education Center, we concluded that the students should receive the robotics lessons as a form of active learning, like project-based learning, to get the students involved in their understanding of the material.

Project-Based Learning

Project-based learning is a student-centered teaching method that allows the students to learn through the analysis and examination of engaging real-world problems. Project-based learning is a teaching method that provides students the opportunity to think critically, analyze problems, and find appropriate learning resources⁶.

Project-based learning provides the students with a deeper understanding of the material that is being taught. It also provides them with real-world examples that equip them with the ability to see the applications of the material. Teaching a project-based curriculum allows for the students to be more in charge of their own learning. It also allows for them to work in groups, reflect on their work, distribute roles, and give presentations⁷. This prepares the students for the workforce, as many STEM fields are project oriented.

Since this teaching method is more student-centered, educators can step into the role of a project guide and advisor. They facilitate the information through projects to make

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⁶ R Pucher, A Mense and H Wahl, How to Motivate Students in Project Based Learning, https://ieeexplore.ieee.org/ezproxy-web-p-u01.wpi.edu/stamp/stamp.jsp?tp=&arnumber=1146878&tag=1
⁷ Dr. Shaban Aldabbus, PROJECT-BASED LEARNING: IMPLEMENTATION & CHALLENGES, https://www.researchgate.net/profile/Shaban-Aldabbus/publication/328368222_PROJECT-BASED_LEARNING_IMPLEMENTATION_CHALLENGES/links/5bc8cd20a6fdcc03c79095e0/PROJECT-BASED-LEARNING-IMPLEMENTATION-CHALLENGES.pdf
learning interactive for the students and promote a fun and engaging environment for education. As shown in Figure 1, there are five stages to the process of project-based learning.

**THE STEPS OF PROJECT-BASED LEARNING**

1. **Introduction**
   - Introduce the topic to the learners by activating students prior knowledge

2. **Driving Questions**
   - The learners come up with the driving questions

3. **Development**
   - Students begin the development of their projects

4. **Feedback**
   - Have learners share their projects for feedback from educators and peers to make revisions

5. **Presentation**
   - Have the learners present their work to others

*Figure 2: The Steps of Project-Based Learning*

The first step is introducing the students to the topic. The learners should be introduced to topics by relating it to their prior knowledge and background. This will reinforce the knowledge and allow them a deeper understanding of the material. The learners should then come up with the driving questions for their project. These would be the main issues or issues that their projects would be addressing and can vary per project. After the students have come up with the driving issues for their project, the learners will move into the development of their projects. They should be in groups to promote communication and collaboration. While the students are working on their projects, they should go through the process of feedback. Learners will be able to learn from their educator’s and peer’s feedback and improve upon their projects and improve their circle thinking skills. Lastly the learners
should present their work. This will increase their communication skills as well as give them valuable practice for real world applications.  

A simple example of project based learning that could be applied to a STEM curriculum is that of students building a bridge. Students would start off by learning the engineering behind bridges such as the forces applied to them, loads, and different structural designs. They would then be split into groups and given materials to build a bridge. The lesson can be as complex or simple as needed. Students will then apply the knowledge learned from the bridge lesson to create one themselves. Throughout the building process they should be guided and supported when needed, but overall the project should be completed on their own. If a bridge fails, try asking the student what could have caused the failure to allow for them to assess their knowledge of bridges and learn from the mistakes. Once the bridges are complete students should present their projects. This can be done in a myriad of ways, such as a formal presentation or a competition. An example of a competition could be to apply weight to the bridges and the bridge that is able to hold the heaviest amount of weight would win. It is important for students to discuss why they made certain design choices as well to assure they are applying the knowledge learned in the classroom to the project.

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8 Dr. Shaban Aldabbus, PROJECT-BASED LEARNING: IMPLEMENTATION & CHALLENGES
https://www.researchgate.net/profile/Shaban-Aldabbus/publication/328368222_PROJECT-BASED_LEARNING_IMPLEMENTATION_CHALLENGES/links/5be8cd20a6fdec03c79095e0/PROJECT-BASED-LEARNING-IMPLEMENTATION-CHALLENGES.pdf

9 MATTHEW LYNCH, 7 EXAMPLES OF PROJECT-BASED LEARNING ACTIVITIES
https://www.theedadvocate.org/7-examples-project-based-learning-activities/
Overall, when students are more active in their own learning process they tend to have a deep and more meaningful understanding of the material\textsuperscript{10}. They are also able to take the material that they learned and apply it to real-world problems. This helps the students fully grasp the concept they are learning.

Active Learning

Active learning is much like that of project-based learning such that it promotes a deeper understanding of the material in a non-traditional sense. Active learning is another form of student-centered learning. It is a more passive type of student centered learning compared to project-based learning, but like project-based learning, it allows students to be more involved in the classroom. It is also a teaching method that engages students in the material, through activities that involve classroom discussions, problem solving, writing and reflecting. A study found that active learning can improve examination scores and students’ understanding across all disciplines and in varying class sizes\textsuperscript{11}.

\begin{flushleft}
\textsuperscript{10} Renata Holubova, Effective teaching methods—Project-based learning in physics https://files.eric.ed.gov/fulltext/ED504949.pdf
\textsuperscript{11} Scott Freemana,l, Sarah L. Eddy, Miles McDonougha, Michelle K. Smithb, Nnadozie Okoroafora, Hannah Jordta, and Mary Pat Wenderotha, Active learning increases student performance in science, engineering, and mathematics, https://www.pnas.org/content/pnas/111/23/8410.full.pdf
\end{flushleft}
As shown in Figure 3, there are four steps that aid in the successful implementation of an active learning style teaching method. The first step of this teaching method is to choose meaningful activities and questions\(^\text{12}\). The material is supposed to be engaging for the students and stimulate interest in the topic at hand. The focus of the material should be on the biggest takeaways that the learners should be getting from the lesson. Secondly, an explanation of why the learners are being provided the lesson in such a way will help them have a deeper understanding of why they are doing the activities. Third, the development of the facilitation approach should be completed by the educator. The facilitation of the activities and lessons can vary by topic and level. The main focus of the activities should be to aid the learners in the mastering of the topic at hand. Lastly, gathering and recording feedback will help with the improvement of the curriculum for future uses.

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\(^{12}\) Center for Educational Innovation, [https://cei.umn.edu/active-learning](https://cei.umn.edu/active-learning)
An example of an active learning lesson would be a think-pair-share activity\(^\text{13}\).

Students could be given the topic of motors and the different applications for them. The students would then have a few minutes to write a response on the different applications of motors that they can think of. The students should then be paired up to discuss their responses. After this discussion individual students should be called upon to present their partner’s findings. This activity allows students the opportunity to interact with the lesson as well as work collaboratively.

Active learning provided students the opportunity to apply the knowledge learned in the classroom to applicable activities. It is a less demanding learning style than project-based learning, providing a different type of learning outcome while still engaging learners with the topic of the lesson.

Making Projects Applicable

The projects and activities that the learners undertake should facilitate an active and engaging learning environment for them to build on their knowledge. Using their prior knowledge to introduce new topics reinforces their information as well as encourages interest in the newer topic. Projects should relate to not only the learners’ prior knowledge but also their life experiences. This will promote a deeper interest and investment into the project.

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\(^{13}\) Active Learning Techniques for the Classroom, [https://learninginnovation.duke.edu/resources/art-and-science-of-teaching/active-learning-techniques-classroom](https://learninginnovation.duke.edu/resources/art-and-science-of-teaching/active-learning-techniques-classroom)
RECOMMENDATIONS FOR STEM EDUCATORS

STUDENT INTERACTION GUIDE
Recommendations for Delivering a STEM Education

After conducting a literature review and surveying educators in the greater Worcester, Massachusetts area, our team will provide the following recommendations on how instructors of all skill levels could present an effective STEM lesson:

1. Create interdisciplinary lessons that utilize the students’ creativity and prior knowledge to solve problems that implicate them.
2. Focus all lessons with the students in mind.
   a. How will they perceive the lesson?
   b. How will they solve the problem?
   c. What will each student learn as a result of completing the lesson?
3. Target students with multiple different learning styles specifically experiential learning and transformative learning.
4. Present lessons with enthusiasm, confidence, and flexibility.

1. Interdisciplinary Lessons

One method that instructors can utilize to promote the engagement of the students is to develop interdisciplinary lessons. By definition, interdisciplinary studies involve the combination of two or more academic disciplines into one activity\textsuperscript{14}.

\textsuperscript{14}What is interdisciplinary studies? | cbu online. (n.d.). Retrieved May 9, 2021, from https://www.cbuonline.edu/articles/what-is-interdisciplinary-studies#:~:text=The%20word%20%22interdisciplinary%22%20is%20defined,a%20breadth%20of%20understanding%20of
A principal strength of creating lessons that combine knowledge from multiple subjects is that students can make connections on prior knowledge and utilize those to solve problems in another discipline. STEM, in general, is interdisciplinary as it is a combination of Science, Technology, Engineering & Math. However, instructors can expand upon this by tying in humanities topics. For instance, instructors can give a historical context to a problem that can be solved with a robot like using a robot to pull up water from a well. Furthermore, robotics lessons can be expanded through an interdisciplinary perspective to utilize human-centered design\textsuperscript{15} (Figure 4).

\textbf{Figure 4: Human Centered Design}\textsuperscript{16}


A human-centered design approach is a unique way to develop the students’ problem solving skills. This method helps the students keep in mind the perspective of the people their designs would be aiding. We recommend that Physically Active Youth continue to expand their outreach to the city of Windhoek, and give the students the opportunity to design robots that will help people. The students could have the opportunity to interview the people who would be using their devices to comprehend the problems that their robot would be solving (Inspiration). From there, the instructor could support and help facilitate the different phases of design\textsuperscript{17}: ask, research, imagine, plan, create, test (Ideation), and improve (Figure 5).

One instructor that we spoke to stated that a project that she facilitated had the students use design principles to create a design that gave them an advantage during a sports game. From there, the students had to pick a game, do research on the ways that people lose the game, imagine a solution to those issues, and then simply design a solution that helps them win the game. She stated that this sparked the students’ interest as they had the opportunity to test and implement their devices for something that was fun and didn’t feel like school. Students can design a robot that helps organize papers for a disabled instructor, or construct a robot that helps grab balls at the end of an outdoor activity. The opportunities are endless, all it takes is the right instructor to teach it.

\textsuperscript{17} Engineering design process—Teachengineering. Org. (n.d.). Retrieved May 9, 2021, from \url{https://www.teachengineering.org/design/designprocess}
2. Student-Centered Learning

A benefit of utilizing a student-centered approach is that it helps students develop their critical thinking skills and shows them specific techniques for accessing information they are interested in.

One instructor we spoke to described student-centered learning as “anticipating the way students will perceive, understand, and question the materials we see”. For example, instructors can do this by doing the lessons on their own, to see what could go wrong, and

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18 Engineering design process—Teachengineering.
how to troubleshoot any issues before they occur in the classroom. This would give the instructor the chance to think about how the students would go about solving a problem.

By prioritizing the preparation of lessons, instructors can prepare possible questions the students may have and become a greater resource to them. Student-centered learning should be designed with a very specific objective on what the students should obtain from the lesson\(^9\). By setting key objectives of what you want the students to learn at the end of the lesson, you can monitor their understanding and track if they are comprehending the material correctly. Furthermore, instructors should include the students’ voice across all phases of both lesson design and delivery. The instructor should assure that the lessons focus on the students’ experiences that can be meaningful and relevant to them. Finally, identifying and targeting each student’s individual learning style is another way to promote the students’ advancement in STEM topics.

3. Targeting Students with Different Learning Styles

One approach that an instructor can take to enhance the students’ engagement in STEM topics is to cater to multiple learning styles. This can be done by using a mix of visual & auditory instruction, and by also having physical materials that the students can read and review at a later time. If the students are given a choice in how the material is presented to them, they may respond better to the instruction and be more engaged in the activities.

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\(^9\) What is student-centered learning and why is it important? (2020, August 25). Rethink Together. [https://xqsuperschool.org/rethinktogether/what-is-student-centered-learning](https://xqsuperschool.org/rethinktogether/what-is-student-centered-learning)
Furthermore, instructors can create material that also targets students who learn best from experiential or transformative learning. Experiential learning is a theory that states that true knowledge is “created using knowledge from one’s experiences”. Kolb’s model of experiential learning includes four methods: do, observe, think & plan. This model helps students build skills like collaboration, communication, critical thinking, creativity, and problem-solving. For teaching a STEM curriculum, experiential learning can be applied across various sectors of education like project-based learning or another version of active learning. Engineering design is a fantastic way to build the students’ experience in experiential learning. Through the design process, most lessons that the students learn are from failure and by seeing what does and does not work. However, there are also other learning methods that can equally engage the students as well.

Additionally instructors can utilize transformative learning, a method that focuses on having a student alter their thinking based on new information. Jack Mezirow, the man who founded the theory, stated that “students had important teaching and learning opportunities connected to their past experiences” and later “found that critical reflection and critical review could lead to a transformation of their understanding.” Another application of this theory is lifelong learning and that “our world view is changed the more we learn, and that

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helps us grasp new concepts and ideas. By incorporating lessons that not only build off of students’ prior experience, but allow for a revelation of new understanding, students gain a greater understanding than they would in a traditional classroom setting. The final and most significant aspect that allows for the students’ advancement is the enthusiasm, flexibility, and efficacy of the educator.

4. Attitude of the Educator

One of the most important aspects that lead to a successful delivery of instruction is the attitude and capability of the specific educator. In this case, capability will not be defined as technological knowledge, but moreover an understanding of instructional pedagogy.

Soft skills are a major aspect of comprehension of technical subjects for students but are also equally important for instructors as well. Taking the time to learn the best ways to present to a group of students with enthusiasm and care for the subject material goes a long way in helping the students learn the content. One researcher found that “there were signs that at times teachers were not confident in their implementation of the curriculum…” and “that affected what was accomplished in the class.”

Overall, we recommend that to advance the students’ engagement and participation in STEM fields instructors should create interdisciplinary lessons, teach with the students in


mind, target students with different learning styles, and maintain a positive attitude when interacting with the students. These steps will aid the students in understanding the robotics curricula and will help the teachers strengthen their pedagogy and ability to deliver STEM curricula.
PAY

ASSESSING STUDENTS' KNOWLEDGE

STUDENT INTERACTION GUIDE
Assessing Students’ Knowledge

The assessment of learners' knowledge is an important process in the teaching process. At the beginning of the course, especially if a project-based learning teaching method is being implemented, students should be assessed on their prior knowledge. These assessments can be in the form of tests, activities, or a mixture. To decide what needs to be included in the assessment, it must first be decided what prior knowledge they may need for the course that is being taught.

It is also important to assess the students' understanding of the material throughout the process of the lesson. The assessments of the learners’ progress may present differently per teaching method. For project-based teaching methods, there are a collection of ways to assess the learners' understanding of the material. These could include labs with lab reports, mini-projects, educator and peer reviews of projects, and other forms of assessment. For the active learning method these assessments can be done through written assignments, group activities, and tests.

At the end of the course, the learners should be assessed on the knowledge and progress throughout the course. This could be measured through successful projects, the completion of assignments, or final exams.
PAY

HELPING STRUGGLING LEARNERS

STUDENT INTERACTION GUIDE
Helping Struggling Learners

While the goal is to instruct a lesson that does not leave any of the students behind as topics are discussed, inevitably, there will be some students who miss key points during instruction or have trouble comprehending at the level of the rest of the class. There are many strategies to engage these students, enabling them to catch back up to their peers.

Differentiated instruction is a method by which instructors can address the learning differences in their classroom. By setting goals on a per-student basis instead of only at the class level, students feel more efficacy, and take ownership of their learning\(^{25}\). When goals are tailored to the progress that each individual can be expected to make, it becomes easier to track a student’s improvement, when compared to measuring the student against the rest of the class. A complete classroom running under differentiated instruction can be hard to maintain for a teacher working with many students, so coming up with one set of goals above and one below the average class level can allow for some differentiation, should it be needed.

A process which can work independently, or in conjunction with differentiated instruction, is high segmentation of the course content. Long lessons with many topics covered are difficult for some students to follow, but more importantly, they are harder to gauge progress on. Ideally, in a busy classroom with independent learners, multiple goals are set for the period, and learners may be able to choose the order for some or all of these targets. Again, increasing choice allows the student to gravitate towards the content that engages them. With this approach, an additional benefit arises. Students struggling with one

topic might focus on another goal until more of the class has an understanding with the difficult topic. After switching tasks, students can have more thoughtful questions and conversations, and be willing to ask their peers for help, knowing there are other students with at least a little more experience. It is important to have “stretch” goals that can be targets for students that are able to quickly complete the lesson. Differentiated goals do not necessarily have to be in the same field of instruction. In fact, some teachers find that activities like having students write a story about the work they did can promote deeper reflections for students that may have rushed through concepts, learning just enough to complete the lesson.

In order to best prepare for the questions, problems, and difficulties that some students will bring up, teachers should first do the full lesson on their own, taking note of their own struggles and points where the internet or other resources were used to get assistance with the activity. Especially in a project-based teaching environment, students may need varying attention and guidance, since they are creating, as opposed to memorization or recitation. Students who may excel at tasks where there is a “right answer” are often in need of extra guidance. For these students, additional structure can aid in their ability to complete projects. By providing ways to break down the problem addressed by the project into smaller tasks, students overwhelmed by the many potential solutions to the problem can focus on just one at a time.

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26 Smith, E., Pastor, M. “Engage Me and I Learn” https://doi.org/10.1177/0031721716671905
Role of Inclusion & Diversity in the Classroom

Some learners may be struggling because of exclusion in the classroom. While some forms of exclusion are obvious and can be mitigated by redesigning groups, many are more nuanced. Students may feel excluded from a project due to the context it is presented in as well. For this reason, it is very important to contextualize lessons and projects to the lived experience of one's students. In a classroom with students of various backgrounds and competencies, spending time to ensure groups of students work in an inclusive way is important, and should have class time devoted to this goal.

While cooperation between students may be enough to foster inclusion, teachers have an active role in the process, especially when a student is having many difficulties[^27]. For students with learning disabilities especially, the teacher’s involvement in group reflections leads to better understanding and pride in the work done for all involved. With inclusive learning strategies, students in out-groups or minorities in the classroom have a greater voice. Not only do typically excluded students get to participate in the learning activities of the “mainstream” students, teachers can work with these students to use the opportunity to share a differing perspective to more mainstream students. Exposing students to the diversity of their peers’ life experience and decision-making processes helps to improve interpersonal skills and ultimately lead towards broader perspectives.

IMPLEMENTATION OF GENDER RESPONSIVE TRAINING

STUDENT INTERACTION GUIDE
Implementation of Gender Responsive Training

One way to enhance engagement for women in technical fields is to employ gender responsive training. Gender responsive training refers to “teaching and learning processes that pay attention to the specific learning needs of girls and boys.” These learning needs will be described as the challenges that each gender faces in education and the goal of this training is to fully eliminate any gender bias in the classroom.

Through this document educators will gain proper training to unlearn stereotypes based around gender. In this section, gender responsive training will be described as the difference in learning styles of both genders and preferred modes of delivery & instruction.

1. Learning Styles

Outside of experiential and transformative learning, there are many other different learning styles that students may utilize when reviewing a STEM curriculum. One study explored two different continuums that describe one’s learning style: the active experimentation-reflective observation dimension & concrete experience-abstract conceptualization dimension.

This study was done to see if there was a correlation between one’s learning style and their gender. The active experimentation-reflective observation dimension deals with how an individual uses the information they are being taught. Learners who approach learning


with active experimentation, enjoy physically working with the material to best understand it\textsuperscript{30}. The opposite are described as reflective observers, which are students that prefer to watch an individual and learn best from visual instruction (Figure 6).

The concrete experience-abstract conceptualization dimension focuses on how an individual perceives and understands direction\textsuperscript{31}. This dimension probes the student to focus on the method in which they learn the material. Concrete experience learners are described as “feelers” meaning they base their understanding of the material by their intuition and their emotions. Abstract conceptualization learners are detailed to be “thinkers”, meaning they utilize logic to comprehend new lessons\textsuperscript{32}.

![Figure 6: Domain\textsuperscript{33}](https://www.skillshub.com/what-are-kolbs-learning-styles/)

\textsuperscript{30} Ibid  
\textsuperscript{31} Ibid  
\textsuperscript{32} Ibid  
https://www.skillshub.com/what-are-kolbs-learning-styles/
Those who prefer concrete experience & active experimentation are labeled as accommodators, meaning they are more practical, enjoy planning, and learn best through trial and error. The other side of the spectrum are assimilators who are more observational & and learn best through abstract conceptual styles. Those who have this style of learning use logic and reason to guide their decisions.

This study found that men most often identify as assimilators while women identify with this one the least. Additionally, the study also suggested that females score higher in the concrete learning mode while males typically score best on the abstract conceptualization. Women with a concrete experience learning preference use hands-on experiences to learn and make decisions intuitively. Men who prefer abstract conceptualization tend to think logically. Overall, instructors can utilize this knowledge to best deliver a robotics curriculum through various avenues.

Instructors should present material first through an abstract open-ended problem that provides the students to build strategies and reason (assimilators/males), and from there give the students the opportunity to tinker and learn through trial and error (accommodator/females). If there is a disproportionate amount of students per gender in a classroom an educator can use their independent reasoning to determine how to teach each student in the best way.

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Course Material & Methods of Learning

This same study also compared how gender influences one’s preferred course material. In the survey students were told to choose between four different types of course material preferences: concrete material (data), creative thinking materials (brainstorming), abstract materials (concepts & theories), hands-on materials (experiments).\(^{35}\)

The results truly illustrated how gender influences one’s preferred course material. Primarily, both genders preferred concrete materials and hands-on material at about the same rate\(^ {36} \) (± 3%). The most significant conclusion made from this study is that 15.8% more women prefer brainstorming activities over men\(^ {37} \) (Figure 7). Therefore, when instructing women one could use brainstorming activities to engage females more in a STEM classroom.

![Figure 7: Course Material Preference for Males & Females\(^{38} \)](image)

The next survey probed respondents on their desired methods of learning new content. The modes of delivery are preference facts, connection with related subjects, observe & reflect, test implications, focus on specific problems, work with others, do research, and

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\(^{35}\) Ibib
\(^{36}\) Ibib
\(^{37}\) Ibib
\(^{38}\) Ibib
use experiments\textsuperscript{39} (Figure 6). Overall, 15.8\% more women preferred connection to related subjects (interdisciplinary than men) and 14.7\% more men preferred testing implications over women. Finally, 14.1\% more women observed & reflected to learn the lesson than men. Therefore, we recommend that instructors use interdisciplinary lessons to engage female students in a robotics education. Regarding testing implications, allow male students an opportunity to see how the robots they will build will affect the users, as this tends to allow them to be more engaged in the course material. Lastly, having a space for female students to reflect on their work after the course is done could give them a chance to finalize learning new material and put together more connections in the material.

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|c|c|c|c|}
\hline
 & \multicolumn{2}{|c|}{Gender} & \multicolumn{2}{|c|}{Major} & \multicolumn{2}{|c|}{Non-STEM} \\
 & Male & Female & STEM & & & \\
\hline
Preference Facts & 60 & 25.8 & 92 & 29.7 & 74 & 24.3 & 61 & 20.9 \\
Connections with Related Subjects & 55 & 23.6 & 122 & 39.4 & 63 & 20.7 & 37 & 12.1 \\
Observe and Reflect & 78 & 11.4 & 79 & 25.5 & 96 & 31.5 & 71 & 23.3 \\
Test Implications & 95 & 24.1 & 29 & 9.4 & 114 & 37.4 & 116 & 38.0 \\
Focus on Specific Problems & 85 & 24.1 & 44 & 14.2 & 108 & 35.4 & 99 & 32.5 \\
Work with Others & 86 & 24.1 & 66 & 21.3 & 104 & 34.1 & 81 & 26.6 \\
Do Research & 96 & 24.1 & 42 & 13.5 & 114 & 37.4 & 106 & 34.8 \\
Use Experiments & 89 & 24.1 & 57 & 18.4 & 92 & 30.2 & 015 & 34.4 \\
\hline
\end{tabular}
\caption{Methods of Learning New Content Preferences for Males and Females (Note that respondents could choose more than one method.)}
\end{table}

\textit{Figure 6: Methods of Learning New Content Gender Based}\textsuperscript{40}

Overall through this section, we provided recommendations to STEM instructors in ways that they can best engage different genders in technical studies. We believe that these techniques should be used in conjunction with one another to assure that students do not feel excluded in lessons.

\textsuperscript{39} Ibib
\textsuperscript{40} Ibib
Conclusion

Over the course of this guide, we discussed the different ways for educators to improve their classroom environment. Educators who are able to successfully implement these techniques are able to take their instruction to the next level, elevating the students’ experience and learning throughout a lesson.

Classroom management skills allow instructors to have more control in the classroom, leading to more efficient teaching as less time is spent away from the lesson. Being able to implement project-based learning and other active learning techniques also allows for students to form stronger connections with the material ultimately giving them a better understanding of the material. Additionally, successfully assessing students’ ability to grasp and understand the material will allow educators to know when they are able to move onto the next lesson and when they need to go back and reteach material from a previous section.

Being able to teach lessons such that the most students are able to understand it is vital for educators. As such, we made recommendations on how instructors can teach students with different learning styles. While it is difficult to teach things only one way and have every student understand, it is possible to combine materials that cater to multiple different learning styles. Planning a lesson so that material is delivered several times, in multiple ways, allows for more students to grasp the concepts. If instructors want to learn more about the topics covered in this guide, all resources used when creating it are referenced for further reading.
Appendix G: Professional Development Resource Guides

This document is included beginning on the next page.
Developed for Physically Active Youth

Professional Development Resource Guide

How to Design Curriculum Development and Do Research

John Benoit, Elizabeth DiRuzza, Andrew Fisher, and Daniel Marsh
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Introduction

Through this guide, instructors will have access to a consolidated set of resources to develop their own lessons to make the robotics program more sustainable. In the case that they want to expand past previously created curricula, they will now have the framework and structure to create these lessons. Furthermore, we also detailed the best practices for researching materials for new curricula and methods to assess it.

The curriculum development methods that we detailed in this document are backward design, successive approximation model, and the design thinking method. Backward design has the instructor think ahead to what objectives they want the students to learn from the lesson, and use that understanding to develop the intermediary steps. The successive approximation model is a model that promotes iterative design of curricula, meaning that material should be constantly revised and adapted even through the delivery of the lesson. The final method detailed is the design thinking method which brings the instructor through the design process of a lesson and is very applicable to STEM lessons. These methods are assessed and ultimately we provide recommendations and templates for each method.

Later, we assigned a list of pedagogy resources that defined a list of teacher recommendations from accredited universities and we described the overall research process an instructor could use to construct new material. We utilized resources from the Worcester Polytechnic Institute library department to give recommendations on how to assess material. Finally, we detailed concept mapping, a technique that instructors can use to connect interrelated topics in a visual way that anyone can interpret. On the website for Physically Active Youth, the concept map was live and interactive, however for the case of the document the topics are shown in a single picture.
DEVELOPED FOR PHYSICALLY ACTIVE YOUTH

CURRICULUM DEVELOPMENT

Professional Development Resource Guide
Curriculum Development

Curriculum development is critical to having a successful educational program, ensuring that the goals of the program are transferred to the students. There are many different methods of curriculum development each with their own approach to converting learning objectives into course material. Each of the methods have different strengths and weaknesses.

Through our research we determined that using a combination of two different models allows for the most complete curriculum. The combination of methods that we recommend is Backwards Design and the Successive Approximation Model (SAM). These two methods work very well together as they are able to offset many of each other’s weaknesses and allow the strengths of each method to shine through.

To use them together, backwards design should be used as the framework, giving the curriculum and lessons structure, while SAM acts as the supplemental method used to add a more iterative nature to the process. If instructors feel that SAM is not a model that adds to backwards design in a way that is beneficial to them, we also found that the design thinking method is another strong iterative model.

However, our research indicated that SAM is a stronger method as it is a slightly more iterative and has more potential. The following sections will detail each of the methods, show how they can be integrated into curriculum development and lesson planning, and contain additional resources for additional information on the method.
Backward Design

Backward Design is a model of curriculum development that focuses on in-depth understanding of learning goals.¹ Also known as understanding by design (UbD), it is comprised of three stages (Figure 1): identify desired results, determine acceptable evidence, and plan learning experiences and instruction.² Backward design is set up to promote long term information retention and skill development by determining how students will display mastery of a topic before creating the instructional material.³

![UbD: Stages of Backward Design](image)

*Figure 1: The steps of backwards design*⁴

In the first stage, curriculum designers determine learning goals based on what information is the most important to have a lasting understanding of.⁵ Information should be broken down into three categories, knowledge, skills, and enduring understandings. Knowledge is defined as information students should be familiar with, skills being what students should be able to do, and enduring understanding being the big ideas that students should retain after

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³ “The Fundamentals of Backward Planning.”
⁵ Ibib.
completing the curriculum. The second stage is when curriculum developers “determine how [they will] know if students have achieved [the] desired learning results.” Assessments are broken into two types: performance tasks and other evidence. Performance tasks are “...larger assessments that coalesce various concepts and understandings like large projects or papers.” Other evidence includes traditional homework, quizzes, and tests as well as self-assessments. As the curriculum is developed around performance tasks that encompass multiple topics, students are required to use older information to inform new assignments in a way that traditional assessments would not require. The final stage is when lessons and learning activities are planned to address the goals initially identified. This stage is not as structured as it is up to the curriculum developers and educators to determine what instruction and learning activities are required to achieve the initial goals. This stage is where iterative design takes place, allowing curriculum developers to experiment with different techniques.

Every curriculum development method has strengths and weaknesses, and backwards design is not an exception. Some of the strengths of backwards design are:

- It focuses on student learning,
- It tends to lead to more explicit and transparent instruction and objectives,
- Material tends to be more focused and related, and
- It allows for other styles of curriculum development to be used alongside it to accommodate students.

These strengths are some of the driving forces behind why backwards design has been so successful in education. Having materials that are directed towards encouraging learning and understanding is something that many educators and administrators are looking for in a curriculum. Backwards design facilitates this type of material due to its goal-oriented approach. It is a very overarching method with space within each of its stages to work with different

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6 “The Fundamentals of Backward Planning.”
7 Ibid.
8 Bowen, “Understanding by Design.”
9 Ibid.
10 “The Fundamentals of Backward Planning.”
11 Burnham, “5 Instructional Design Models You Should Know.”
12 Bowen, “Understanding by Design.”
14 Bowen, “Understanding by Design.”
15 Ibid.
methods. This gives educators the ability to combat many of its weaknesses by using methods that are stronger in those areas. While backwards design has a great number of strengths, it is also limited in some ways:

- It is a rather rigid structure without much flexibility for adjustments,\(^1\)
- It is time consuming for educators,\(^2\) and
- It may be impersonal at times.\(^3\)

The biggest drawback of backwards design is how rigid its structure is. However, because we are recommending that it be combined with another more flexible method much of this drawback is mitigated. In places where flexibility is needed, another method can be used instead. The rigidity of backwards design is what makes the method feel impersonal at times, as the design process is focussed on how to best teach the goals rather than how to teach each individual student. To counteract this shortcoming, educators may set individual learning objectives for different groups of students within the program. However, this can lead to the third limitation of backwards design, as identifying more learning objectives and deciding how to teach them adds extra material that needs to be planned and edited. This, however, is an issue with many different methods of curriculum design and is more of a result of education's focus on outcomes.

Integrating backwards design into an educator’s curriculum development repertoire will require practice as the method has many nuances. Applying backwards design to a pre-existing curriculum is one way that an educator could practice using the method. From here, the results of the backwards design process could be compared to the results from previous designs to see how it improved the curriculum and what still needs to be worked on in the backwards design process. Additionally, the use of a template for planning both curriculum and lessons may aid in increasing how quickly backwards design is understood, while also guiding instructors through the steps of the process. Templates for both curriculum design and lesson planning are attached to this guide as well as completed examples of each. Additional resources to further the understanding of the methods are linked below and complete offline versions will be attached to the end of the guide.

\(^{2}\) Ibid.
Additional Resources

This section contains a list of resources on backwards design. These resources were gathered from trusted sources to further explain backwards design and provide additional help while implementing it in the classroom.

1. [https://www.cultofpedagogy.com/backward-design-basics/](https://www.cultofpedagogy.com/backward-design-basics/)
   One educator experiences with backwards design and how backwards design thinking improved their classroom.

2. [https://cft.vanderbilt.edu/guides-sub-pages/understanding-by-design/](https://cft.vanderbilt.edu/guides-sub-pages/understanding-by-design/)
   Vanderbilt University’s backwards design page details the history, methods, and implementation of backwards design including a template for using backwards design.

   This is an article about using the backwards design process.

4. [https://www.wwu.edu/teachinghandbook/course_design/backward_design.shtml](https://www.wwu.edu/teachinghandbook/course_design/backward_design.shtml)
   A short article explaining the backwards design model.

5. [https://fctl.ucf.edu/teaching-resources/course-design/backward-design/](https://fctl.ucf.edu/teaching-resources/course-design/backward-design/)
   A video detailing backwards design.
Successive Approximation Model

The successive approximation model, SAM, is a curriculum design method that was adopted from technical fields such as computer science. SAM consists of three iterative phases each consisting of several stages. The three phases are preparation, iterative design, and iterative development as seen in Figure 2.

The preparation phase gives stakeholders the opportunity to decide on the goals of the curriculum and how it will be delivered. In this preparation phase the first outlines of the curriculum may even take shape. The next phase is the iterative design phase which is made up of designing, prototyping, and evaluating stages that are repeated in an iterative manner. The designing stage is where concepts from the preparation phase are given more substance and become concrete ideas. In the prototyping stage, the designs are created and tested in a rough unfinished state so that they can be evaluated. This evaluation informs the curriculum designers as to which parts of the design work and which need to be redesigned. Once the design has been evaluated, the designers will begin to do any redesigns that they see necessary, and this process is iterated until the curriculum is ready to go into development.

Figure 2: The phases of the successive approximations model

The final phase of SAM, the development phase, is a “constant loop of developing, implementing, and evaluating” the curriculum. During this phase it is important that there is

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21 Allen, “The SAM Model.”
22 Herrholtz, “Rapid Instructional Design With SAM.”
23 Herrholtz, “The SAM Model.”
24 Herrholtz, “Rapid Instructional Design With SAM.”
always a usable section of the curriculum so that instructors and learners can interact with it and give feedback. As SAM was adopted from technical fields, there are additional release stages that come at the end of the development phase. The release stages are in place to give the curriculum developers an opportunity to make final changes to the curriculum if minor issues arise. By this point in the model there should not be any major flaws in the curriculum but the feedback in the release phase ensures that the developers did their jobs well.

SAM is another method that has more strengths than weaknesses and its strengths are very effective at covering for the weaknesses of backwards design. Some of the strengths of SAM are:

- It is very flexible and iterative allowing for all options to be explored,
- It avoids major reworks after development is completed, and
- It leads to clearly defined and well put together course materials.

The biggest weakness of backwards design is that it is not flexible and SAM is extremely flexible allowing it to pick up the slack for backwards design in the curriculum development process. Additionally, as backwards design is a less iterative model major reworks are more common, by integrating SAM principles with those of backwards design these major reworks can be avoided. SAM is not perfect however and it does have some limitations:

- It lacks of structure,
- It may be rushed at times, and
- It is repetitive in nature.

SAM does sometimes lack structure as it is a very free flowing method that focuses on generating ideas and testing them. When partnered with backwards design this actually becomes a strength as backwards design provides the structure that allows for flexible idea generation to flourish as it has the defined steps that help curriculum designers stay on topic and focused on

25 Allen, “The SAM Model.”
27 Ibid.
28 Ibid.
29 “The SAM (Successive Approximation Model) Approach to ELearning.”
the learning objectives. Seeing as SAM relies on rapid prototyping it can move very quickly at times. This allows for ideas to be tested quickly, but may lead to team members becoming confused. As a method on its own, SAM has many merits and its strengths far outweigh its limitations; when used with backwards design the strengths of the two methods support one another and allow for both methods to be more effective.

Integrating SAM into an instructor’s curriculum development arsenal is arguably the easiest of any of the methods discussed in this guide. This is because it can be the most easily applied to pre-existing curriculum. As SAM is an iterative process, any curriculum can be reviewed and updated using SAM. By taking an existing curriculum and beginning with either the evaluate or review stages of the process, the SAM process can be applied. SAM is full of tables and guides on how to plan and develop content for courses and these resources are also important to understanding and integrating SAM into the classroom.
Additional Resources

This section contains a list of resources on SAM. These resources were gathered from trusted sources to further explain backwards design and provide additional help while implementing it in the classroom.

   Allen interactions is a website run by the creators of the successive approximation model. This page contains a breakdown of the steps of SAM. For more information on SAM explore the site further.

2. [https://dli.kennesaw.edu/resources/idmodels/sam.php](https://dli.kennesaw.edu/resources/idmodels/sam.php)
   Kennesaw State University’s guide to the successive approximation model.

   A blog post about implementing SAM to create usable training materials.

4. [https://www.findcourses.com/prof-dev/l-d-articles/addie-vs-sam-which-is-better-11516](https://www.findcourses.com/prof-dev/l-d-articles/addie-vs-sam-which-is-better-11516)
   A short post comparing SAM to another curriculum development technique highlighting SAM’s strengths.

   A blog post about using SAM to address the weaknesses of older curriculum development methods.

   An article about how to implement SAM in the classroom.

   A breakdown of the steps of SAM.
Design Thinking Method

The design thinking model of curriculum design focuses on understanding a learner’s needs and developing specific solutions to address those needs. This model is comprised of five stages: empathize, define, ideate, prototype, and test as seen in Figure 3. The first stage, empathize, requires the curriculum developer to “gain an empathic understanding of the problem [they] are trying to solve.” The empathize stage is a research phase when as much information on the problem should be gathered. The second stage, define, is where the core problems are identified to be solved. Throughout this method, it is important to frame information in a human-centric manner as to make the students the most important people in the curriculum.

The third stage, ideate, is when solutions should be brainstormed using a variety of techniques. This gives many possible ways to address the problem and students will have access to the best methods. Prototyping is when specific solutions are designed and tested, this is a stage where the teaching materials for the curriculum would be made. This is also when feedback would be received from stakeholders as to whether or not the materials being created

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32 Burnham, “5 Instructional Design Models You Should Know.”
33 Ibid.
35 Ibid.
36 Ibid.
37 Burnham, “5 Instructional Design Models You Should Know.”
successfully teach the curriculum. The final stage is to test, this is where the curriculum is implemented in the classroom and feedback is received from students.

While the design thinking method is a strong method of curriculum design, it has more weaknesses than the previous methods discussed. That being said, design thinking still has many strengths including:

- It is flexible and iterative,
- It encourages taking multiple approaches to the same problem, and
- It is student-focused.

Like SAM, design thinking is created to be an iterative process giving designers the ability to try different things. This gives designers a chance to approach an issue from multiple angles, trying to understand different ways the students may understand concepts. The other upside to design thinking is that it focuses on the students throughout the planning process. Design thinking is a strong secondary choice because of its flexibility, student-centered focus, and focus on different perspectives. However, design thinking also has additional drawbacks that SAM and design thinking do not. Some of the more glaring drawbacks are:

- It is more complicated to understand,
- There are often challenges integrating it into pre-existing curricula,
- It often becomes limited over time, and
- It can become a lengthy process.

Design thinking is based on more complex psychology than other curriculum development techniques and is harder to grasp. Because of its more complex nature, it is harder to use to update existing curricula, as it is more likely to clash with proven methods that designers are too stubborn to change. Its complexity also often leads to it being more constrained as it is used more as designers attempt to simplify making it a much less iterative and effective

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39 Burnham, “5 Instructional Design Models You Should Know.”
40 Friis Dam and Siang, “5 Stages in the Design Thinking Process.”
42 Friis Dam and Siang, “5 Stages in the Design Thinking Process.”
44 “Innovate with Design Thinking: Pros and Cons.”
45 Hobcraft, “The Limitations, Criticisms, and New Pathways for Design Thinking- Part One.”
46 “Innovate with Design Thinking: Pros and Cons.”
method. As a result, it can also become a long drawn out process without the same amount of effectiveness as other longer curriculum design methods.

Additional Resources

This section contains a list of resources on the design thinking method. These resources were gathered from trusted sources to further explain backwards design and provide additional help while implementing it in the classroom.

   This is a journal article discussing how to use the design thinking method including extensive research on the methodology, implementation, and outcomes. It includes a “curriculum innovation canvas” to help instructors plan curriculum using design thinking.

2. https://drawbackwards.com/blog/drawbackwards-design-thinking-process
   A guide to one organization’s approach to using design thinking.

   A two part investigation on design thinking and how it must progress to stay relevant in the ever changing environment of curriculum design.

4. https://www.interaction-design.org/literature/topics/design-thinking
   An article about what design thinking is and how to use it.
Lesson Planning and Curriculum Development Templates

Using a new curriculum development technique without a template for the first time can be overwhelming. As such, we collected well developed curriculum and lesson planning templates for each of the curriculum development methods discussed in this guide. Each template is accompanied by either a completed example of the template or a version of the template with descriptions in each step.

Backwards Design

The following templates have been reformatted to fit within this guide. Template one originated from Vanderbilt University’s Center for Teaching’s page on Understanding by Design and template two originated from modelteaching.com in their article titled Backwards Design in Lesson Planning.
### Stage 1 – Desired Results

<table>
<thead>
<tr>
<th>ESTABLISHED GOALS</th>
<th>Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Students will be able to independently use their learning to...</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNDERSTANDINGS</td>
</tr>
<tr>
<td><em>Students will understand that...</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Students will know...</em></td>
</tr>
</tbody>
</table>

### Stage 2 – Evidence and Assessment

<table>
<thead>
<tr>
<th>Evaluative Criteria</th>
<th>Assessment Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PERFORMANCE TASK(S):</td>
</tr>
</tbody>
</table>

| OTHER EVIDENCE: |

### Stage 3 – Learning Plan

*Summary of Key Learning Events and Instruction*
## Stage 1 – Desired Results

<table>
<thead>
<tr>
<th>ESTABLISHED GOALS</th>
<th>Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>The enduring understandings and learning goals of the lesson, unit, or course.</td>
<td><strong>Students will be able to independently use their learning to...</strong></td>
</tr>
<tr>
<td></td>
<td>Refers to how students will transfer the knowledge gained from the lesson, unit, or course and apply it outside of the context of the course.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UNDERSTANDINGS</strong></td>
</tr>
<tr>
<td>Students will understand that...</td>
</tr>
<tr>
<td>Refers to the big ideas and specific understandings students will have when the complete the lesson, unit, or course.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Students will know...</strong></td>
</tr>
<tr>
<td>Refers to the key knowledge students will acquire from the lesson, unit, or course.</td>
</tr>
</tbody>
</table>
### Stage 2 – Evidence and Assessment

<table>
<thead>
<tr>
<th>Evaluative Criteria</th>
<th>Assessment Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PERFORMANCE TASK(S):</strong></td>
<td>Refers to the authentic performance task(s) that students will complete to demonstrate the desired understandings or demonstrate they have attained the goals. The performance task(s) are typically larger assessments that coalesce various concepts and understandings like large projects or papers.</td>
</tr>
<tr>
<td><strong>OTHER EVIDENCE:</strong></td>
<td>Refers to other types of evidence that will show if students have demonstrated achievement of the desired results. This includes quizzes, tests, homework, etc. This is also a good point to consider incorporating self-assessments and student reflections.</td>
</tr>
</tbody>
</table>

### Stage 3 – Learning Plan

*Summary of Key Learning Events and Instruction*

This stage encompasses the individual learning activities and instructional strategies that will be employed. This includes lectures, discussions, problem-solving sessions, etc.
**Directions:** Use this planning worksheet to follow the three steps of the backwards design process in order to plan an effective lesson.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Lesson Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content Standard</td>
<td></td>
</tr>
</tbody>
</table>

**Step One: Write a Student-Centered Learning Objective** – Must be specific, measurable, and clearly stated.

<table>
<thead>
<tr>
<th>Behavior – WHAT the learner will be able to do.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Includes a verb!</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition – HOW the learner will perform the behavior. Refers to a tool, reference, aid, or context they will or will not be able to use.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Criterion – How WELL the learner must perform to demonstrate content mastery. Refers to a degree of accuracy, number of correct responses, or time limit.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Learning Objective – Put all three parts together.</th>
</tr>
</thead>
</table>
**Step Two: Create a Plan for Assessment** – Used to gather information about a student’s progress towards mastery of the learning objective, help the teacher identify what instruction is working well and what needs refinement, and informs the students about their learning.

<table>
<thead>
<tr>
<th>Type of Assessment</th>
<th>Options to Consider</th>
<th>Specific Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diagnostic / Pre-Assessment</strong> – Used to check prior knowledge before a lesson.</td>
<td>□ Self-Assessment&lt;br&gt;□ Writing Prompts&lt;br&gt;□ Running Records&lt;br&gt;□ Performance Task&lt;br&gt;□ Other</td>
<td></td>
</tr>
<tr>
<td><strong>Formative</strong> –</td>
<td>□ Learning / Response Log&lt;br&gt;□ Admit / Exit Ticket&lt;br&gt;□ Think / Pair / Share&lt;br&gt;□ One Minute Paper&lt;br&gt;□ Other</td>
<td></td>
</tr>
<tr>
<td><strong>Summative</strong> –</td>
<td>□ End of Unit Tests&lt;br&gt;□ Final Exams or Mid-Term Exams&lt;br&gt;□ State Tests&lt;br&gt;□ Culminating Project&lt;br&gt;□ Portfolio</td>
<td></td>
</tr>
</tbody>
</table>
### Step Three: Choose Learning Strategies and Activities

How you present new content to your students, and how your students will actually interact with the content. Add additional rows as needed.

<table>
<thead>
<tr>
<th>Strategy 1:</th>
<th>Activities Planned:</th>
<th>Active</th>
<th>Passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Direct Teach</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Demonstration</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Cooperative Learning</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Discover /Inquiry-Based Learning</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Project-Based Learning</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Other: ___________________________</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategy 2:</th>
<th>Activities Planned:</th>
<th>Active</th>
<th>Passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Direct Teach</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Demonstration</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Cooperative Learning</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Discover /Inquiry-Based Learning</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Project-Based Learning</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Other: ___________________________</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategy 3:</th>
<th>Activities Planned:</th>
<th>Active</th>
<th>Passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Direct Teach</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Demonstration</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Cooperative Learning</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Discover /Inquiry-Based Learning</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Project-Based Learning</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ Other: ___________________________</td>
<td>☐</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

21
Template 2 Example

**Directions:** Use this planning worksheet to follow the three steps of the backwards design process in order to plan an effective lesson.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Math</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lesson Date</strong></td>
<td>5/8/21</td>
</tr>
</tbody>
</table>

**Content Standard** Determine the volume of a rectangular prism with whole number side lengths in problems related to the number of layers times the number of unit cubes in the area base

**Step One: Write a Student-Centered Learning Objective** – Must be specific, measurable, and clearly stated.

<table>
<thead>
<tr>
<th>Behavior – WHAT the learner will be able to do.</th>
<th>Calculate volume of a rectangular prism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Includes a verb!</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition – HOW the learner will perform the behavior.</th>
<th>When given a formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refers to a tool, reference, aid, or context they will or will not be able to use.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Criterion – How WELL the learner must perform to demonstrate content mastery.</th>
<th>4 out of 5 examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refers to a degree of accuracy, number of correct responses, or time limit.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Learning Objective – Put all three parts together.</th>
<th>When given the correct formula, students will accurately calculate the volume of a rectangular prism at least 4 out of 5 times.</th>
</tr>
</thead>
</table>
**Step Two: Create a Plan for Assessment** – Used to gather information about a student’s progress towards mastery of the learning objective, help the teacher identify what instruction is working well and what needs refinement, and informs the students about their learning.

<table>
<thead>
<tr>
<th>Type of Assessment</th>
<th>Options to Consider</th>
<th>Specific Plan</th>
</tr>
</thead>
</table>
| **Diagnostic / Pre-Assessment** – Used to check prior knowledge before a lesson. | □ Self-Assessment  
☑ Writing Prompts  
□ Running Records  
□ Performance Task  
□ Other | Student warm-up -- journal prompt: Write what you know about volume of a 3-D shape. |
| **Formative** – Used during a lesson to check progress, identify any misconceptions, and give feedback to students. | □ Learning / Response Log  
☑ Admit / Exit Ticket  
□ Think / Pair / Share  
□ One Minute Paper  
□ Other | Students will complete an exit ticket with 2 sample volume problems.  
Students will solve sample problems on a white board. |
| **Summative** – Used at the end of a lesson to check student mastery of the objective. | ☑ End of Unit Tests  
□ Final Exams or Mid-Term Exams  
□ State Tests  
□ Culminating Project  
□ Portfolio | Students will have a 10 question quiz at the end of the week, 5 questions will involve calculating volume. |
### Step Three: Choose Learning Strategies and Activities

Choose the learning strategies and activities to present new content to your students and how your students will actually interact with the content. Add additional rows as needed.

<table>
<thead>
<tr>
<th>Strategy 1:</th>
<th>Activities Planned: ☑Active ☐Passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>☑ Direct Teach</td>
<td>Students will use base 10 blocks to find the area of a 2X4 rectangle (8 units). They will then explore what happens when they stack more 2X4 rectangles on top of the original. (Two levels - volume is 16 units, 3 levels - volume is 24 units, etc.). Students will be encouraged to try other example until the concept of volume is solidified in their mind.</td>
</tr>
<tr>
<td>☐ Demonstration</td>
<td></td>
</tr>
<tr>
<td>☐ Cooperative Learning</td>
<td></td>
</tr>
<tr>
<td>☑ Discover /Inquiry-Based Learning</td>
<td></td>
</tr>
<tr>
<td>☐ Project-Based Learning</td>
<td></td>
</tr>
<tr>
<td>☐ Other: ___________________________</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategy 2:</th>
<th>Activities Planned: ☐Active ☑Passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>☑ Direct Teach</td>
<td>Students will watch a Khan academy video introducing volume. This will then lead to a class discussion about the formula for volume and how it is related to the hands-on work they just did. (<a href="https://www.khanacademy.org/math/basicgeo/basic-geo-volume-sa/volume-rect">https://www.khanacademy.org/math/basicgeo/basic-geo-volume-sa/volume-rect</a> prism/v/ how-we-measure-volume)</td>
</tr>
<tr>
<td>☐ Demonstration</td>
<td></td>
</tr>
<tr>
<td>☐ Cooperative Learning</td>
<td></td>
</tr>
<tr>
<td>☐ Discover /Inquiry-Based Learning</td>
<td></td>
</tr>
<tr>
<td>☐ Project-Based Learning</td>
<td></td>
</tr>
<tr>
<td>☐ Other: ___________________________</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategy 3:</th>
<th>Activities Planned: ☑Active ☐Passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Direct Teach</td>
<td>Independent practice worksheet, with sample problems done on their own for a quick check for understanding.</td>
</tr>
<tr>
<td>☐ Demonstration</td>
<td></td>
</tr>
<tr>
<td>☐ Cooperative Learning</td>
<td></td>
</tr>
<tr>
<td>☐ Discover /Inquiry-Based Learning</td>
<td></td>
</tr>
<tr>
<td>☐ Project-Based Learning</td>
<td></td>
</tr>
<tr>
<td>☑ Other: <strong><strong>Practice</strong></strong>____</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategy 3:</th>
<th>Activities Planned: ☐Active ☑Passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Direct Teach</td>
<td>Students will complete an exit ticket as they leave class. The 3 questions on the exit ticket will be formatted similarly to the questions on the district unit assessment.</td>
</tr>
<tr>
<td>☐ Demonstration</td>
<td></td>
</tr>
<tr>
<td>☐ Cooperative Learning</td>
<td></td>
</tr>
<tr>
<td>☐ Discover /Inquiry-Based Learning</td>
<td></td>
</tr>
<tr>
<td>☐ Project-Based Learning</td>
<td></td>
</tr>
<tr>
<td>☑ Other: <em><strong><strong>Assessment</strong></strong></em>___</td>
<td></td>
</tr>
</tbody>
</table>
Template 3

This template is formatted in a print only version by its creators. A PDF version of it is available at [https://www.sfsu.edu/~teachers/download/Inquiryframework.pdf](https://www.sfsu.edu/~teachers/download/Inquiryframework.pdf) to be printed. This template is accompanied by instructions that would allow the template to be used as a guide for planning material following the steps provided in another document or on a sheet of paper.

Successive Approximation Model

SAM does not have traditional lesson planning templates however when creating the method Michael Allen created many charts and models detailing how to implement SAM. These charts and models can be found in *Leaving ADDIE for SAM* or on Michael Allen’s website ([alleninteractions.com](http://alleninteractions.com)). Not all charts and models are available on the website.

Design Thinking Method

The curriculum innovation canvas from *The Curriculum Innovation Canvas: A Design Thinking Framework for the Engaged Educational Entrepreneur* has been reformatted to fit in this guide.
General Pedagogy Resources

Below is a list of resources that have been recommended by educators and curriculum development experts throughout the creation of this guide. Each is a vast well of knowledge created and curated by educational professionals.

1. [www.cultofpedagogy.com](http://www.cultofpedagogy.com)
   a. Cult of Pedagogy is an organization that posts materials about teaching and classroom. Run by former and current teachers, it has blogs, podcasts, and videos covering many different subjects surrounding teaching.

2. [www.edutopia.org](http://www.edutopia.org)
   a. Run by the George Lucas Educational Foundation, Edutopia is a site that shares how educators “can adopt or adapt best practices,” and “tell[s] stories of innovation and continuous learning” according to their website.

3. [inservice.ascd.org](http://inservice.ascd.org) and [ascd.org](http://ascd.org)
   a. ASCD is an international nonprofit education association that provides educators with materials to empower their learners. It has resources created by people who work in various educational fields designed to aid educators in creating a better classroom.

Also many universities and colleges have fantastic resources associated with their teaching programs. Many of these resources are available for free on their websites and can be found with a quick google search. The universities’ materials used or referenced in this guide are:

- [Vanderbilt University](http://vanderbilt.edu),
- [Western Washington University](http://wwu.edu),
- [University of Central Florida](http://centralflorida.edu),
- [Kennesaw State University](http://kennesaw.edu),
- Northeastern University, and
- [San Francisco State University](http://sfstate.edu)

While not every one of these schools have a complete, easily accessible online source of pedagogy material the resources they provide are all very informational. These are also not the only universities or colleges with strong education programs and other schools resources may prove equally valuable.
Any of the sources or resources referenced or suggested in other sections may also have additional resources available, however these materials have not been vetted to the same level as material directly included in the guide.
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RESEARCH METHODS

Professional Development Resource Guide
Research Methods

A large portion of creating a new curriculum for learners is finding sources. Researching is an important tool that if implemented properly, can provide a myriad of resources and tools. Proper researching methods and techniques are important concepts to grasp in order to find reliable and credible sources. It is important to have dependable sources when it comes to curriculum design to assure learners are receiving accurate and viable information.

How to Begin Researching

The first step to conducting research is to have a topic in which to research. Having a solid understanding of what needs to be researched is important. Without a solid understanding, it may be hard to find proper sources that relate to the topic. Once a generalized topic is decided upon, the next step would be to narrow down the focus. One way to narrow down the generalized topic would be to use concept mapping. Concept mapping is a tool that helps one visualize the related terms and material to the general topic. It is a way to organize all the subsets of the topic that may be useful. Take the simple example of the concept map for animals shown in Figure 4. It starts with the general topic of all animals, then goes to more specifics by breaking it into animal classes, and then more specific within those classes.

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47 Kevin J. Miller, Concept Mapping as a Research Tool to Evaluate Conceptual Change Related to Instructional Methods, https://doi.org/10.1177/0888406409346149
Once a background and idea of concepts is established, the next step in researching is collecting sources. The first step to finding sources is to know where and how to find them. There are countless free online resources to find reliable sources. Part of finding the sources is searching through online search engines. Many popular search engines have techniques to narrow down and refine searches, to provide the most accurate and useful sources. A few common techniques that popular search engines use include, but are not limited to: quotation marks, dashes, limiting the dates of creation, and boolean phases such as AND and OR. When applied, these techniques will provide the optimal options for sources best related to the topic at hand.

Overall research is about going more in depth into a topic that is of interest. When applying research to curriculum development it is important to make sure the sources are reliable and credible.

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49 Proceed Innovative, Refine your Search with These Google Search Tricks, https://www.proceedinnovative.com/blog/google-search-tricks/
Investigating Sources

With the wide variety of information available it is easy to find sources. But not all sources may be reliable or unbiased. When it comes to researching for curriculum design, it is imperative to find credible sources to provide learners with the most accurate information. To ensure the sources are within this scope, there are ways to vet a source to provide learners with the most accurate and insightful.

One common method for researching is known as the C.R.A.P. method as shown in Figure 5. The “C” of the C.R.A.P. method stands for currency. This section of the research method focuses on making sure the information is current. For example if one was to look up the design of a car engine, they could find a model from 1989. Although this is not completely incorrect it is not the most relevant and car engines have evolved since 1989. It is important to make sure the information found is current to provide learners with the most up to date information.

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The “R” of the C.R.A.P. method stands for reliability. To provide learners with correct information, one must first have reliable sources. One way to check if a source is reliable is to see if the information provided in the source is made up mostly of opinion or facts. If a majority of the source is opinion, it may not be reliable. If it is mostly facts and provides references and sources it is more reliable and has a higher chance of providing accurate information.

The “A” of the C.R.A.P. method stands for authority. The author of the source is an important detail when it comes to reliability and accuracy. One must analyze the author and ask questions such as: who is the author? What are their credentials? Are their advertisements on the site? Are they reputable? These kinds of questions help narrow down the credibility of the author and decide if they are a reliable source. For example if one was researching dinosaurs, an article
or journal written by a Paleontologist would be more reliable then an article written by an enthusiast. Searching for an author is an important step in the researching process.

The “P” in the C.R.A.P. method stands for purpose/point of view. This section focuses on any biases of the author and what the purpose of the source is. If it is an article that is an advertisement for cologne, but one is researching the history of cologne, then it may not be the best source. Another part of this section is to think about if the source is mostly fact or opinion. Sources should be mostly facts or opinions that are based in facts and research. The purpose of the source is an important quality to consider when researching.

The C.R.A.P. method is a research guide that arms the researcher with techniques to properly understand how to critically analyze sources. It provides the researcher with possible questions to vet sources and test the credibility of them. Finding reliable and accurate information to provide students is an important part of curriculum development. When finding sources, it is important to analyze them and approach the search critically.

We have provided an Information Search Process guide for vetting sources\textsuperscript{51}. This guide provides examples of questions that should be asked when looking for sources. It will provide guidance on finding reliable and credible sources. It is a tool for a more effective researching process.

\textsuperscript{51} Gordon Library. (2021). ID2050 library research assignment – Information search process [worksheet]. Worcester Polytechnic Institute
# Information Search Process Tool

**Instructions:**
1. Choose five different search tools (such as google scholar and differing data bases).
2. Use each search tool to look for a curriculum topic information source (such as a journal article, book, news article, etc.) for a total of five (5) sources – one using each search tool.
3. Answer the questions about each source and the search process.

<table>
<thead>
<tr>
<th>Information Source One</th>
<th>Information Source Two</th>
<th>Information Source Three</th>
<th>Information Source Four</th>
<th>Information Source Five</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. a. Where did you find the source (Google Scholar, a database, etc.)?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Why did you choose this search tool?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. a. What search words or phrases did you use?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Did you use any filters or Advanced search features to refine your results? If yes, which ones?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. a. Why did you choose this source? What was your process of elimination for articles you did not select?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Which aspect of the project, such as technical, social, or local, does this source meet, and why?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Continuing Your Research:**
1. In addition to the keywords listed above, what other keywords will you use as you continue to look for sources? Possible other key words:
2. In addition to the search tools listed above, what other search tools will you use as you continue to look for sources? List at least one example for each of the following categories:
   a. Library database:
   b. Website for an organization, association, or government agency that is doing similar work to your project:
   c. Newspaper from the geographic region:
**Information Search Process Tool-Filled Out Example**

**Instructions:**
4. Choose five different search tools (such as google scholar and differing data bases).
5. Use each search tool to look for a curriculum topic information source (such as a journal article, book, news article, etc.) for a total of five (5) sources – one using each search tool.
6. Answer the questions about each source and the search process.

<table>
<thead>
<tr>
<th>Information Source One</th>
<th>Information Source Two</th>
<th>Information Source Three</th>
<th>Information Source Four</th>
<th>Information Source Five</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.</strong> a. Where did you find the source (Google Scholar, a database, etc.)? b. Why did you choose this search tool?</td>
<td>a. JSTOR b. It is a reliable database of academic journals and resources</td>
<td>a. JSTOR b. It is a reliable database of academic journals and resources</td>
<td>a. Gordon library search b. It is a reliable source that gives me access to a wide range of resources</td>
<td>a. Google Scholar b. It has a wide range of academic sources</td>
</tr>
<tr>
<td><strong>3.</strong> a. Why did you choose this source? What was your process of elimination for articles you did not select? b. Which aspect of the project, such as technical, social, or local, does this source meet, and why?</td>
<td>a. This source was chosen because it spoke of how engineering and robotics can impact children’s learning and gave a specific example of how it was implemented in schools b. This would fail</td>
<td>a. This source was chosen because it was the most relevant source to what was being</td>
<td>a. This source was chosen because it was most relevant to the aspect of the Namibian school</td>
<td>a. It is another case study about a robotics event held in African schools. It demonstrates an approach like that of</td>
</tr>
<tr>
<td></td>
<td>under the technical aspect of the project because it is related to the goal of the project.</td>
<td>looked for. Other suggested articles were either not related to the schooling in Africa or focused on more focused aspects of African school systems. b. This article relates to the local aspect of the project for it gives a deeper understanding of the school systems we will be working with.</td>
<td>system that we would be working with. b. This source relates to the local and social aspect of the project. It relates to the social aspect due to its background of teachers overall and local due to its specific look into Namibian teachers.</td>
<td>how similar projects were implemented in areas similar to where we will be working</td>
</tr>
</tbody>
</table>

Continuing Your Research:
1. In addition to the keywords listed above, what other keywords will you use as you continue to look for sources?
Possible other key words: Namibian learning, aspects of teaching, teaching teachers, teacher professional development courses.

2. In addition to the search tools listed above, what other search tools will you use as you continue to look for sources? List at least one example for each of the following categories:
a. Library database: SAGE Journals
b. Website for an organization, association, or government agency that is doing similar work to your project:

c. Newspaper from the geographic region: https://www.namibian.com.na/
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SKILL MAPPING

Professional Development
Resource Guide
Concept Mapping for Skills and Lessons

The concept mapping method, common for organizing research, can be applied in many ways. When applied to course topics for the VEX IQ curriculum created by WPI, as well as instructional videos targeted at educators and the lessons included in the official VEX IQ “STEM Labs” curriculum, planning lessons around concepts that span these 3 becomes easier. For each piece of content, a set of connections are made. Each item has a list of other lessons or topics that it depends on. In the visualization used, the concepts or lessons are shown as circles. The arrows on the diagrams point from formative concepts towards lessons that build on these concepts. Inevitably, more content will be found that should go in the curriculum. When new lesson ideas come up, using the concept mapping strategy, the instructor can quickly figure out what steps need to be taken to integrate a lesson, by looking back down the tree to find what other lessons are relevant.

Figure 6: Concept map of included content
Why map out skills to teach?

Concept maps are a powerful tool in organizing thoughts and ideas. When it comes to organizing lessons, they are an equally strong tool. When choosing an order to teach lessons in, it is important to make sure that students have requisite knowledge for a lesson before they are asked to complete it. If a student does not have the necessary knowledge to complete the lesson without assistance, it becomes a hindrance to a large portion of the class when the instructor must take time out of the lesson to review. In order to minimize the amount of time spent reviewing past topics, it is important to occasionally use skills derived from said topic, and to try and introduce new topics immediately after reinforcing the skills and concepts they depend on. Through use of a concept map, the instructor can determine which concepts must be "fresh" in students' minds for them to best understand the explanation of the lesson topic.

How to use the tool:

In order to use the concept mapping tool, visit the webpage with the embedded tool. Concepts can be moved and reordered by clicking and dragging them. The connections to their related topics are force-driven, so the concept map should settle in a way that minimizes on-screen distance between related topics.
Conclusion

The purpose of developing this document was to provide the instructors with knowledge on developing new curricula. Through understanding this document, instructors will have a new organizational tool to help them develop their own lessons. In the case that these educators want to expand past the material created by previously, they will now have the framework and structure to create these lessons.

Our research showed that the most efficient method of curriculum design is not one single method, but rather a combination of two or more methods. The purpose of this is to create balanced lessons as each design method has different strengths that can counteract each other's weaknesses. We found that a combination of a method that has more structure to it combined with a method that is more iterative in nature is the strongest combination of methods. We recommend that educators use a combination of backward design and the successive approximation model (SAM). Backward design was consistently held in high regard by the instructors that we interviewed as it has a strong structure designed to ensure that students reach learning objectives while having some flexibility in lesson planning.

Later, we assigned a list of pedagogy resources that defined a list of teacher recommendations from accredited universities and we described the overall research process an instructor could use to construct new material. We utilized resources from the Worcester Polytechnic Institute library department to give recommendations on how to assess material. Finally, we detailed concept mapping, a technique that instructors can use to connect interrelated topics in a visual way that anyone can interpret. On the website for Physically Active Youth’s robotics program, the concept map was live and interactive, however for the case of the document the topics are shown in a single picture.