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Teachers and Counselors: Building Math Confidence in Schools

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ABSTRACT

Mathematics teachers need to take on the role of counselors in addressing the math anxious in today's math classrooms. This paper looks at the impact math anxiety has on the future of young adults in our high-tech society. Teachers and professional school counselors are encouraged to work together to prevent and reduce math anxiety. It is important that all students feel confident in their ability to do mathematics in an age that relies so heavily on problem solving, technology, science, and mathematics. It really is a school's obligation to see that their students value and feel confident in their ability to do math, because ultimately a child's life: all decisions they will make and careers choices may be determined based on their disposition toward mathematics. This paper raises some interesting questions and provides some strategies (See Appendix A) for teachers and counselors for addressing the issue of math anxiety while discussing the importance of developing mathematically confident young people for a high-tech world of STEM.

Keywords: math anxiety, teaching, strategies, counselors, STEM

THE TRUTH IS THAT MATH ANXIETY EXISTS: AN INTRODUCTION

Today math teachers in the United States and many other countries around the world almost have to take on the role of counselors in their classrooms to address the many students who dislike or are fearful of mathematics. Mathematics teachers are encouraged to work with professional school counselors in helping to address the many math anxious students in today's schools. In an age of STEM (Science, Technology, Engineering, and Mathematics), it is critical that teachers today had better prepare all students to succeed with and be confident in their ability to do mathematics so to compete globally. It really has become a pandemic in our society where so many young people and adults have negative feelings and poor past experiences with mathematics instruction (Beilock & Willingham, 2014; Boaler, 2008; Dowker, Sarkar, & Looi, 2016; Geist, 2010). Some voices from young people in the USA about mathematics include the following:

> *"I really don't like math, but I do okay." – Julie, 14*
>
> *"I just don't like math, it's the same thing and big numbers, and I don't like big numbers." – Brian, 13*
>
> *"I have lots of math anxiety, for me math is very confusing." – Samantha, 19*
>
> *"Frustration, sweaty palms, and fear are words I would use to describe what math does to me." – Heather, 34*
>
> *"When I hear the word math I get goosebumps." – Starry, 9*

Figure 1. Photo about Math Troubles in Society, Photo-J. Furner

"Math makes me shake." – Seth, 10

"When I think of math I don't get nervous I get bored." – Chad, 11

The statement on the marquis above (see **Figure 1**) and the comments from the young people above in regards to their feelings toward mathematics are just a sampling of how many children and adults feel about math today in the 21st century. Anyone today can easily take an informal poll on the street and find that most respondents will not report positive experiences, feelings, and attitudes toward mathematics. However, we are now living in an age that depends so heavily on one being good at mathematics and problem solving. We are living in a world in which our students will soon be competing with young people from all parts of the globe for jobs (Neunzert, 2000). It is imperative that our students develop positive dispositions toward mathematics and the sciences in an information age of which has become so technologically oriented. Young people today need to be well prepared in the areas of math, science, and technology for all career choices specially now with the emphasis on STEM in our society. Nurses, engineers, architects, lawyers, teachers, along with many other fields will continue to use more advanced forms of technology that require one to know more mathematics and problem solving to perform their jobs more effectively. Sequencing, ordering, patterning, logic, spatial sense, and problem solving are some of the truly basic skills that all careers require (NCTM, 2000). A student's confidence and ability to do mathematics and apply these skills in many diverse settings is essential for success; therefore, our young people need to be well prepared to do the mathematics of the 21st century.

According to Reuters (2007) and the American Association for the Advancement of Science in San Francisco, math anxiety saps working memory to do mathematics. Often times, worrying about doing math takes up a large part of a student's working memory, which then spells disaster for the anxious student who is taking high-stakes tests. Today math teachers from around the world almost have to take on the role of counselors in their classrooms to address the many students who dislike or are fearful of mathematics. Mathematics teachers are encouraged to work with school counselors in helping to address the many math anxious students in today's schools. It really has become a pandemic in our society where so many young people and adults have negative feelings and poor past experiences with mathematics instruction.

Ruff & Boes (2014) found that low math achievement is a recurring weakness in many students. They see math anxiety as a persistent and significant theme to math avoidance and low achievement. Causes for math anxiety include social, cognitive, and academic factors. Interventions to reduce math anxiety are limited as they exclude the expert skills of professional school counselors to help overcome this nervousness often times. The effectiveness of a school counseling small group intervention to reduce math anxiety and increase achievement in fifth grade participants were some of the results of their research study. This study found that math teachers need to pair up with school counselors to address the math anxiety in their students. This paper also supports this approach to math instruction.

Steen (1999) points out "national and international studies show that most U.S. students leave high school with far below even minimum expectations for mathematical and quantitative literacy." Neunzert (2000) found in this research that today humans need to understand ourselves as MINT-professionals, where MINT is M=mathematics, I=informatics, N=natural sciences, T=technology. Neunzert (2000) contends that mathematics is critical for people living in the 21st Century for them to be successful. Neunzert concluded that teacher's ad our society as a whole need to encourage our students in all countries to study more mathematics and to see it as a tool for success in life.

Math anxiety remains a perplexing, persistent, and only partially understood problem from which many people suffer, National Council of Teacher of Mathematics (NCTM) (1991, p. 6) says, "Classrooms should be mathematics communities that thrive on conjecturing, inventing, and problem solving, and that build mathematical confidence. Unfortunately, in this day and age many young people and adults do not feel confident in their ability to do math.

Mathematics anxiety in students has become a concern for our high-tech world not just the USA (Brown, Brown, & Bibby, 2008). Is it possible that only about 7 percent of Americans have positive experiences with mathematics from kindergarten through college study (Jackson, C. D. & Leffingwell, 1999)? Burns (1998) in her book *Math: Facing an American Phobia* tackles an interesting subject and has found that two-thirds of American adults fear and loathe math. Whether it is 93% or two-thirds of Americans experiencing negative math experiences it is clear that there is a problem and we need to do something about it as educators. If math anxiety is such a problem, why isn't as much being done about it today?

Evidence of students' poor attitudes and high levels of anxiety toward math is abundant (Brown, Brown, & Bibby, 2008). In the midst of a technological era, declining mathematics (math) scores in the USA on the Scholastic Aptitude Test (SAT) have been widely publicized, today many students are not performing well in math (Brown, Brown, & Bibby, 2008). In their paper, they have found that many young people have perceived difficulty and lack of confidence as critical reasons for learners not continuing with math courses, and that perceived hate and boredom, and lack of real-life relevance, as other factors for not pursuing math fields and study (Brown, Brown, & Bibby, 2008). Some reports have shown that American students rank last when compared with students from all other industrialized countries on 19 different assessments. The Third International Mathematics and Science Study (TIMSS) has shown a trend in U. S. students' math scores as they decline as students increase in age group from grade four to grade twelve compared to many other countries (Schmidt, 1998). What is happening to our students that so many of them lose interest in math and lack the confidence to do and take more math classes? Parker (1997) addresses this issue by interviewing math anxious individuals who share the causes for their math anxiety and what they did to help come up with solutions to their problem, which can serve as strategies described later in this paper.

To address the issue of math anxiety, classroom teachers need to team up with school counselors. Teachers need to be sensitive to students' needs, feelings, and experiences with mathematics. Brigman & Campbell (2003) have found based on their research that when school counselors team up with classroom teachers they can have a profound effect on student achievement scores. A counselors' psychological expertise can serve as a real asset to classroom teachers and students who struggle with a fear of mathematics or poor past math instruction experiences. As educators, we need to remember that not all students are alike, yet all students deserve equal opportunities in the mathematics classroom (NCTM, 2000). A math teachers' job is not only to teach the subject area. One of National Council of Teachers of Mathematics goals for all learners was that as math teachers, we should help students become confident in their ability to do mathematics (NCTM 1989). NCTM (1989, 2000) believes that students should be exposed to numerous and varied interrelated experiences that encourage them to value math, to develop mathematical habits of the mind, they should understand the role of math in human affairs: they should be encouraged to guess, read, write, make conjectures and make errors so that they can gain confidence to solve complex problems. With this in mind, it is clear then that math teachers are not only instructional leaders, they are also counselors and confidence builders for their clients, their students.

MATH ANXIETY DEFINED

What is math anxiety? Well, to put it simply, it is anxiety when confronted with math, especially about one's own performance in solving math problems. It can range from slight nervousness to all-out panic. This anxiety makes it more difficult for students to focus in class, learn math, and solve math problems. Frequently students would rather give up than have to face their fears. This means that they never get better at math and can therefore never overcome their anxiety. If this anxiety is not addressed, the student may suffer from this anxiety for their entire life, even beyond their time in school. Math anxiety is a well-documented phenomenon that has affected our society for over sixty years, and not enough is being done to address it in our classrooms or in the way we teach math (Beilock & Willingham, 2014; Boaler, 2008; Dowker, Sarkar, & Looi, 2016; Geist, 2010). Negative attitudes toward mathematics and math anxiety are serious obstacles for students in all levels of schooling today (Geist, 2010). Beilock and Willingham (2014) state that "Because math anxiety is widespread and tied to poor math skills, we must understand what we can do to alleviate it" (p. 29).

Math anxiety is caused by a combination of external and internal factors; however, we cannot change internal factors within the student, so as teachers it makes more sense to focus on what we can control (Chernoff

& Stone, 2014). Studies show that math anxiety is caused primarily by the way the student learns math: the type of authority the teacher uses, an emphasis on right answers and fear of getting wrong answers, requirements that the student respond with an answer sooner than he or she might be ready, and exposure to the rest of the class and their potential condemnation of a student who responds poorly, in short the traditional way of teaching math (Chernoff & Stone, 2014, Finlayson, 2014). Traditional teaching emphasizes:

- "Basic skills
- Strict adherence to fixed curriculum
- Textbooks and workbooks
- Instructor gives/students receive
- Instructor assumes directive, authoritative role
- Assessment via testing/correct answers
- Knowledge is inert
- Students work individually." (Finlayson, 2014)

Unfortunately, these methods can cause and increase math anxiety in the classroom (Finlayson, 2014).

Math anxiety can also be transmitted and learned from others, usually from parent to child or teacher to student, but occasionally student to student. If someone teaching math, whether to their own child or to a class, experiences math anxiety, they are more likely to rush through things in order to "get it over with." They wouldn't be sure of their methods, so they would focus more on the correct answer. Like the student with math anxiety, they are also likely to become exasperated and give up rather than continue helping the student. This teaches the student that math is something to be afraid of and that, if they are not good at it, their parent or teacher will become angry with them and potentially leave. They also learn in class that, if their peers see that they are bad at math, they will be ridiculed publicly. Embarrassment is a very big deal for children, especially in middle and high school.

Another problem for those who suffer from math anxiety is the nature of anxiety itself. According to Rubinstein et al (2015), anxious individuals tend to focus on negative stimuli more than positive stimuli, essentially making themselves more anxious. The same thing is true of individuals with math anxiety; the only difference is that for people with math anxiety, math is negative stimuli (Rubinstein et al, 2015). This suggests that math anxiety could be handled through therapies designed to lessen anxiety, such as cognitive behavioral therapy and exposure therapy (exposing a person little by little to the thing that they are afraid of) (Rubinstein et al, 2015). While this is not something that a teacher could do with a full class to manage, it is something that tutors could be trained to help with; naturally, a licensed therapist would be the best option, but not all therapists are trained to help students with math. A combination of the two fields would be optimal.

Math anxiety remains a perplexing, persistent, and only partially understood problem from which many people suffer, NCTM (1991, p. 6) says, "Classrooms should be mathematics communities that thrive on conjecturing, inventing, and problem solving, and that build mathematical confidence. Unfortunately, in this day and age many kids and adults do not feel confident in their ability to do math. Mathematics anxiety in students has become a concern for our high-tech world. Is it possible that only about 7 percent of Americans have positive experiences with mathematics from kindergarten through college study (Jackson, C. D. & Leffingwell, 1999)? Burns (1998) in her book *Math: Facing an American Phobia* tackles an interesting subject and has found that two-thirds of American adults fear and loathe math. Whether it is 93% or two-thirds of Americans experiencing negative math experiences it is clear that there is a problem and we need to do something about it as educators. If math anxiety is such a problem, why isn't as much being done about it in our schools?

PREVENTING MATH ANXIETY

There are many things schools can do to help prevent math anxiety from occurring in students. It really is a complicated matter and may involve what happens to kids in and outside of the classroom. Teachers and parents can play a critical role in helping to develop positive dispositions toward math. It is important that teachers check for these positive attitudes and dispositions toward mathematics at an early age. Often students can develop such anxieties toward math very early on in their math classrooms due to poor teaching, drill and practice, strained testing situations, parental and teacher insecurities about their own math abilities, etc. The elementary and middle school years are critical to developing positive perceptions toward mathematics in children. The NCTM (2000, 1995, & 1989) has made recommendations for preventing math anxiety with recommendations such as:

- accommodate different learning styles
- create a variety of testing environments
- design positive experiences in math classes
- remove the importance of ego from classroom practice
- emphasize that everyone makes mistakes in mathematics

- make math relevant
- let students have some input into their own evaluations
- allow for different social approaches to learning mathematics
- emphasize the importance of original, quality thinking rather than rote manipulation of formulas; and emphasize the importance of original, quality thinking rather than rote manipulation of formulas
- characterize math as a human endeavor.

What it really comes down to is that teachers must employ best practices for teaching mathematics. Zemelman, Daniels, and Hyde (2012) based on a culmination of research have put together what is considered the "best practices" for teaching mathematics that all math teachers should incorporate into their instruction which include: (a) use of manipulatives (make learning math concrete); (b) use cooperative group work; (c) use discussion when teaching math; (d) make questioning and making conjectures a part of math; (e) use justification of thinking; (f) use writing in math for: thinking, feelings, and prob. Solving; (g) use problem-solving approach to instruction; make content integration a part of instruction; (h) use of calculators, computers, and all technology; (i) being a facilitator of learning; and (j) assess learning as a part of instruction. Also, see Appendix A for a summary, which includes strategies/key ideas for preventing math anxiety.

REDUCING/OVERCOMING MATH ANXIETY

Reducing math anxiety is much different from preventing math anxiety. Teachers need to work with school counselors and to act as psychologist or counselors themselves to help lower or overcome such anxiety toward math in their students. It is critical that math teachers team up with school counselors to address reducing math anxiety in their students. Researchers in math anxiety propose systematic desensitization (Furner, 1996; Schneider & Nevid, 1993; Hembree, 1990; Trent, 1985; Olson & Gillingham, 1980) as an effective approach for helping people reduce their math anxiety. Systematic desensitization in the context of math anxiety may be defined as a gradual exposure to the mathematical concepts that are causing students to become distressed and teaching them how to cope with that fear. Each time they are exposed to the math they fear, they should improve in their techniques in coping with their anxious feelings. Being able to talk about their past history with math and releasing their anger, hatred and fear of the subject may be therapeutic. Through this counseling approach, students come to understand that their anxiety was a learned behavior, they were not born with this feeling, and they can be taught to overcome it by consistently implementing their self-monitoring strategies to become less anxious. Davidson and Levitov (1999) advocate the use of relaxation in conjunction with repeated positive messages and visualizations to reduce math anxiety.

How is math anxiety reduced? Teachers and counselors must help students understand how their math anxiety was created. According to Hackworth (1992), math teachers can use the the following activities to assist in reducing math anxiety: (a)discuss and write about math feelings; (b) become acquainted with good math instruction as well as study techniques; (c) quality studying; recognize type of information learning; (d) be an active learner and create problem solving techniques; (e) evaluate your own learning; (f) develop calming/positive ways to deal with fear of math and doing math: visualization, positive messages, relaxation techniques, and frustration breaks; and lastly (g) gradual repeated success in math builds confidence (See Appendix A). Tobias (1987) suggests that one way for students to reduce math anxiety is to recognize when panic starts, to identify the inactiveness in their analytic and retrieval systems, and to clear up the static without ceasing to work on the problem.

Ooten (2003) in her book, *Managing the Mean Math Blues,* outlines a four-step method for managing a persons' math anxiety. Ooten believes that a person who suffers from math anxiety needs to first lay the groundwork by coming to terms with their feelings and challenge their current beliefs and realize they are not alone; second, one must change their thoughts and negative thinking and use intervention strategies to improve ones thinking that they can be successful at math; third, one needs to know thyself, it is important that one knows his/her learning style/mode and that he/she apply approaches to doing math by successful people; and lastly fourth, once one has gained some confidence and strategies for doing mathematics they then must apply what they learned and actually do the math.

Campbell (2001), a school counselor, has developed a nine-session math confidence building group therapy workshop for students to help in overcoming and coping with their math anxiety. Campbell suggest that students who are math anxious should go through the following nine sessions with the math teacher and possibly a counselor:

Session 1: Drawing and goal setting in math
Session 2: Discussing past math feelings
Session 3: Learning to relax and cope with math fear and begin using "Math Feelings Journal"
Session 4: Using clay to vent anger from past math experiences and discuss ideal math classroom

Session 5: Self-talk to develop positive thoughts about math learning
Session 6: Success imaging and creative visualizations, relaxation techniques to work toward math success
Session 7: Creating a math rap song about something the students like in math, continue to use the "Math Feelings Journal"
Session 8: Create a math fun mural to focus on positive aspects of math
Session 9: Creating confidence cards and sharing with group to discuss success with math

Campbell (2001) suggests that while conducting the nine-session therapeutic math confidence workshop the teacher and counselor need to be sensitive to students needs and feelings and that each student may progress at his/her own pace. Also, teachers and counselors need to incorporate booster sessions to maintain student confidence, she suggests that students should be encouraged to regularly use a "Math Feelings Journal" to manage anxious feelings when they crop up.

BUILDING MATH CONFIDENCE

Teachers and school counselors should work together to do many things in the classrooms to help build their students math confidence. One practical idea for teachers and students is for teachers to assess their students' dispositions toward math at the beginning of a school year by having them complete the following Mathitude Survey:

Mathitude Survey

1. When I hear the word math I …………
2. My favorite thing in math is …………
3. My least favorite thing in math is …………
4. If I could ask for one thing in math it would be …………
5. My favorite teacher for math is ………… because …………

Journal writing in math classrooms has become an everyday event for many students. Students use journals to express their understanding of mathematical concepts. Journals can also be used to allow students to share feelings and experiences with math. Students are rarely asked how they feel about learning about different concepts and branches of mathematics. Teachers can get really get a better understanding and feel for any frustration student are feeling.

The following sample list of journal/discussion question math teachers may use with students to write about alone or to discuss and share together as a class or small group. Teachers must realize that for students to overcome or have their math anxiety reduced, they must first initiate this form of therapy by allowing students to express their true feeling about math and how they arrived at such a disposition toward math:

Journal/Discussion Questions for Students in Groups

1. Pretend that you have to describe mathematics to someone. List all the words or phrases you can think of that you could use.
2. Imagine yourself doing or using math either in or out of school. What does doing or using math feel like? Describe.
3. If math were a color, an animal, music, or food what would it be?
4. For me math is most like. Why?
5. Describe how you feel in a math class.
6. Are you the type to do well in math class? Why or why not?

The picture book, *Math Curse* (Scieszka & Smith, 1995), addresses the issue of math anxiety. It is an excellent example of how educators have come to terms with the fact that not all people feel confident in their ability to do math. When Mrs. Fibonacci, an elementary school teacher, tells her class that they can think of almost everything as a math problem, one student becomes overwhelmed by the scope of math. This math anxiety becomes a real curse. However, the student eventually realizes that math is everywhere and there is no way of escaping it in daily life; therefore, the math anxious youngster recognizes math as a means of making one's life easier. This book may be used as a form of bibliotherapy to prompt discussion on the topic of math anxiety and allow other students to discuss their feelings on the topic to compare to the character in the book.

Hebert and Furner (1997) outline specific lessons and activities to help in reducing math anxiety with activities such as: role playing feelings and experiences with math classes/teachers; using a math journal for students to write in, so they may describe their feelings while doing math problems, writing letters to the main character of the book *Math Curse;* writing math anxiety poems and rap songs about math and/or their anxiety toward mathematics; writing a letter to and advice column about their math anxiety to get advice; designing anti-math anxiety bumper stickers to be plastered on their school lockers, providing students with a daily self-affirmation statement; providing students an opportunity to create original radio or television advertisements for a national anti-math anxiety campaign; and providing students an opportunity to select an artistic medium (i.e. magazine photo collage, penciled sketch) to illustrate their math anxiety to name a few. Hebert and Furner feel that teachers need to take the time in their math instruction to address such affective aspects of learning mathematics so that students can come to terms with their feelings toward mathematics.

In one study, Jackson & Leffingwell (1999), cited that only 7 percent of the population in their study reported having positive experiences with mathematics from kindergarten through college. The study cited that there are many covert (veiled or implied) and overt (apparent and definite) behaviors exhibited by the math instructor in creating math anxiety in students. Things like difficulty of material, hostile instructor behavior, gender bias, perceptions of uncaring teacher, angry behavior, unrealistic expectations, embarrassing students in front of peers, communication and language barriers, quality of instruction, and evaluation methods of the teacher. Math instructors' behaviors and teaching methods can be hurtful and negative to students learning math. Math teachers need to take an active role in reducing performance anxiety in math. It is not uncommon that a student will say, "I like the class because of the teacher." It is often because the teacher knows how to present developmentally the subject matter, creates a learning environment conducive to learning with compassion, has high expectations for all students without regard to gender, race, or language barriers, and uses a variety of assessment methods and teaching styles to best reach all students. As we enter the new millennium, it is a teacher's obligation to see that all students are prepared for a high-tech society where one cannot afford to not feel confident in their ability to do math.

TEACHERS AND COUNSELORS: HOW DO WE FIX MATH ANXIETY IN OUR SCHOOLS?

To put it simply: better teaching. Finlayson (2014) suggests the constructivist style of teaching which emphasizes these main ideas:

- "Begin with the whole – expanding to parts
- Pursuit of student questions/interests
- Primary sources/manipulative materials
- Learning is interaction – building on what students already know
- Instructor interacts/negotiates with students
- Assessment via student works, observations, points of view, tests. Process is as important as product
- Knowledge is dynamic/change with experiences
- Students work in groups"

This style of teaching is very different from the traditional style which can cause and increase math anxiety. The constructivist style is much less intimidating and does not emphasize timed assessments or correct answers; instead, it focuses on the process of doing mathematics. Students are also likely to feel more engaged in class due to the more participatory style of teaching, making them want to work harder, instead of "getting it over with" heedless of how this affects their performance.

However, frequently the problems in the classroom that cause math anxiety are due to a teacher with math anxiety (Chernoff & Stone, 2014). These teachers choose the easiest ways of teaching (rote memorization of formulas, practice using one method to get one right answer, timed tests, etc.) in order to minimize their own math anxiety, not realizing that they are passing their own anxiety onto their students (Chernoff & Stone, 2014). Therefore, we must first remove math anxiety from teachers, so they may teach their students not to experience math anxiety. Math is not inherently frightening, but that is the message that is told to many children, even from their parents and teachers.

As mentioned previously, math anxiety is a form of anxiety and therefore treatable through the same types of therapy we use to treat general anxiety and phobias (Rubinstein et al, 2015). This may prove especially helpful for adults with math anxiety, especially teachers; by working to handle their own math anxiety, adults would be able to prevent transmission of their anxiety to their children or students (Chernoff & Stone, 2014).

Ruff & Boes (2014) claim in their research that teachers need to become and work with counselors to address math anxiety in their students. They found that so often math anxiety interventions seem to neglect the psychological and emotional aspects of math anxiety. Schools employ professional school counselors who are uniquely trained to assist students with a wide range of academic and personal/social stressors and could be effectively used to help students cope with math anxiety yet a further search of the literature related to school counseling and anxiety varied in suggestions to assist kindergarten to college students, but such interventions are not as common.

Ramirez, Gunderson, Levine, & Beilock (2013) concluded in their research how critical it is for schools and teachers to address math anxiety when people are young. They found that high working memory (WM) individuals tend to rely on WM-intensive solution strategies, and these strategies are likely disrupted when WM capacity is coopted by math anxiety. They argue that early identification and treatment of math anxieties is important because these early anxieties may escalate and eventually lead students with the highest potential to avoid math courses and math-related career choices. So, when teachers team up with school counselors they can better then identify such students early on.

Woodard (2004) found and recommends from her research that counselors can help math anxious students. She feels they can interview math-anxious students and make a math-anxiety problem known to teachers before a student begins a course. Furthermore, she feels that math anxiety scores and school and college placement scores could be compared to determine if a relationship exists between them. This could help educators determine if math anxiety has an effect on placement testing and if alternative means need to be used when placing students in developmental math courses. She emphasizes teachers work with counselors to identify and more effectively math anxious students so to address and prevent and/or reduce math anxiety in students.

SUMMARY

Teachers of mathematics need to take on the role of counselors to address the math anxious students they have in their classrooms. Based on research from above it is then recommended that math teachers team up with professional school counselors to employ the many suggestions and recommendations mentioned in this article in their classrooms/schools to help prevent and reduce math anxiety. Teachers may also want to work with school counselors as well as encourage their schools to have family math nights where parents come with children and together they can "do math" and see its importance and value in life. As a society, we must work together to extinguish the discomfort that our children are having toward mathematics in an age of STEM. It is important that all students feel confident in their ability to do mathematics in an age that relies so heavily on problem solving, technology, science, and mathematics. It really is a teachers' obligation to see that their students value and feel confident in their ability to do math, because ultimately a child's life: all decisions they will make and careers choices may be determined based on their disposition toward mathematics. As educators, we must make the difference in our children's attitudes toward math. Educators along with society as a whole need to strive toward creating mathematically literate and confident young people for the new millennium. It would be nice to hear more young people and adults when asked how they feel about math say, "Math is my favorite subject" or "I am great at math!" or "I can solve any word problem!" or "I am planning to go into a STEM field."

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APPENDIX A

Tips for Building Math Confidence in Young People

Mathematics teachers need to be counselors too ………..

What NCTM says about Mathematics Anxiety and Dispositions Toward Mathematics

Standard 10: Mathematical Disposition (NCTM 1989)
As mathematics teachers, it is our job to assess students' mathematical disposition regarding:

- confidence in using math to solve problems, communicate ideas, and reason;
- flexibility in exploring mathematical idea and trying a variety of methods when solving;
- willingness to persevere in mathematical tasks;
- interests, curiosity, and inventiveness in doing math;
- ability to reflect and monitor their own thinking and performance while doing math;
- value and appreciate math for its real-life application, connections to other disciplines and cultures and as a tool and language.

A Synthesis on How to Reduce Math Anxiety

1. Psychological Techniques like anxiety management, desensitization, counseling, support groups, bibliotherapy, and classroom discussions.
2. Once a student feels less fearful about math he/she may build their confidence by taking more mathematics classes.
3. Most research shows that until a person with math anxiety has confronted this anxiety by some form of discussion/counseling no "best practices" in math will help to overcome this fear.

A Synthesis on How to Prevent Math Anxiety

1. Using "Best Practice" in mathematics such as: manipulatives, cooperative groups, discussion of math, questioning and making conjectures, justification of thinking, writing about math, problem-solving approach to instruction, content integration, technology, assessment as an integral part of instruction, etc.
2. Incorporating the NCTM *Standards* and your State Standards into curriculum and instruction.
3. Discussing feelings, attitudes, and appreciation for mathematics with students regularly.

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Mathematical Modeling with Middle School Students: The Robot Art Model-Eliciting Activity

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ABSTRACT

Internationally mathematical modeling is garnering more attention for the benefits associated with it. Mathematical modeling can develop students' communication skills and the ability to demonstrate understanding through different representations. With the increased attention on mathematical modeling, there is a need for more curricula to be developed, implemented, and assessed. This study details the mathematical understandings that a diverse class of urban middle school students demonstrated on a mathematical modeling activity focused on geometry and measurement. At times students had difficulties in communicating clearly but based on the structure of the activity students were able to self-assess the quality of their communication and work towards improvement. The groups in the class were able to develop methods for how to program a robot to recreate a picture, though improvements could be made to the design of the activity. Teachers can use MEAs and mathematical modeling as formative assessment to build on students' understandings and further develop ideas that the teacher has in mind to pursue. Such assessment provides a rich basis for identifying evolving mathematical understandings that can be further developed.

Keywords: middle school, mathematical modeling, model-eliciting activities, geometry

INTRODUCTION

Internationally, mathematical modeling is gaining more of a presence in school standards and international documents. In Australia, mathematical modeling is part of the concepts and techniques that students should know in the National Mathematics Curriculum (Australian Curriculum, Assessment and Reporting Authority, 2015). In Sweden, mathematical modeling is one of seven mathematical abilities to develop in students. Germany includes mathematical modeling as one of six compulsory competencies (Blum & Borromeo Ferri, 2009). The PISA 2012 mathematics framework describes mathematical literacy with many connections to mathematical modeling.

> *Mathematical literacy is an individual's capacity to formulate, employ, and interpret mathematics in a variety of contexts. It includes reasoning mathematically and using mathematical concepts, procedures, facts and tools to describe, explain and predict phenomena. It assists individuals to recognize the role that mathematics plays in the world and to make the well-founded judgments and decisions needed by constructive, engaged and reflective citizens.* (OECD, 2013, p.25)

Mathematical Modeling is also one of eight Standards for Mathematical Practice in the U.S. Common Core State Standards for Mathematics (Common Core State Standards Initiative, 2010). Since mathematical modeling is often done in groups it develops students' ability for mathematical description, explanation, justification, and argumentation (English & Watters, 2005). It can also increase their meta-representational knowledge; students' explicit recognition of why they represented their model in the way they did (English, 2010).

With the increased attention on mathematical modeling there is a need for curriculum to be developed and tested that is based on research-based principles (Stohlmann & Albarracin, 2016). This study describes the mathematical understandings that a diverse group of urban middle school students demonstrated on a mathematical modeling activity as part of a Saturday STEM (Science, Technology, Engineering, and Mathematics) program offered at a large research university in the Southwestern part of the United States.

THEORETICAL FRAMEWORK

There are several mathematical modeling approaches that encompass a range of theoretical and pragmatics perspectives (Kaiser & Sriraman, 2006). One of these perspectives is the contextual modeling perspective that has subject-related and psychological goals. This perspective draws on the design of activities that motivate students to develop the mathematics needed to make sense of meaningful situations. A perspective that is aligned with contextual modeling that was used in this study is the Models and Modeling Perspective (MMP).

One of the most important characteristics of the MMP is that experts in fields tend to not only do things differently, but they also see or interpret things differently. The development of these interpretation systems or models are an invaluable part of what it means to develop expertise in a field (Lesh, Carmona, & Moore, 2009). In general, "models are conceptual systems (consisting of elements, relations, operations and rules governing interactions) that are expressed using external notation systems, and that are used to construct, describe, or explain the behaviors of other system(s)-perhaps so that the other system can be manipulated or predicted intelligently" (Lesh & Doerr, 2003, p.10). In the MMP the abilities, processes and constructs to solve "real life" problems are used throughout the learning process and not only after the content is learned (Lesh & Zawojewski, 2007). As students iteratively develop their solutions during modeling activities, so teachers can go through an iterative process in their development of these activities.

Aligned with the MMP the definition of mathematical modeling used in this study was that "mathematical modeling is an iterative process that involves open-ended, real world, practical problems that students make sense of with mathematics using assumptions, approximations, and multiple representations" (Stohlmann & Albarracin, 2016, p.1). Mathematical modeling curriculum should have multiple acceptable solutions. Much work done with the MMP draws on Model-Eliciting Activities (MEAs) as the modeling curriculum used.

Model-Eliciting Activities

Model-Eliciting Activities (MEAs) are open-ended, realistic, client driven mathematical modeling activities that were originally designed as an alternative to standardized testing as a way for students to demonstrate mathematical knowledge (Lesh & Doerr, 2003). MEAs are designed based upon six principles (Lesh, Hoover, Hole, Kelly, & Post, 2000).

1. Model Construction: This principle ensures that students are required to construct an explicit description, explanation, or procedure for a mathematically significant situation. This is done through a problem statement that provides students with direction from a client on the focus of the problem.
2. Generalizability: In MEAs students are required to produce solutions that are shareable with others and modifiable for other closely related situations. In the problem statement students are directed to develop a model for the immediate situation being addressed and also generalize their model for other closely related situations.
3. Model documentation: This principle ensures that students are required to create some form of documentation that will reveal explicitly how they are thinking about the problem. This is done through student presentations in which they describe their developed model and the process of how they came up with it, which often involves multiple representations. It can also be accomplished through having students write letters, to the client in the problem, that details their model and rationale for the model.
4. Reality: MEAs should be posed in a realistic context and be designed so that students can interpret the activity meaningfully from their different levels of mathematical ability and general knowledge. MEAs can often be used across different grades of students because they assess what students know and understand on mathematical content that can develop across grade levels.
5. Self-assessment: This principle ensures that the activity contains criteria the students can identify and use to test and revise their current ways of thinking. Students should be able to self-assess how well their model meets the needs of the client. This can be done through information or data provided in the MEA, feedback from other group members and other groups, and testing the model with new data or for closely related situations.

Table 1. Messages or questions for students when doing mathematical modeling

Before mathematical modeling
There is more than one right answer to this problem.
There is not one type of person that is the best at mathematical modeling. Everyone can contribute.
Make sure everyone in your group understands your solution.
Use multiple ways to demonstrate your solution: pictures, graphs, symbols, words, or equations.
During mathematical modeling
Keep in mind what the problem is asking you to do.
Make sure everyone in your group understands your solution.
Does your solution make sense in the realistic situation?
Can your solution be improved?
Is your mathematics correct?
Before group presentations
Listen carefully to each group and think of a question to ask them.
Try to see if there is anything from a group that you can use in your solution.
Look to ensure that each group's mathematics is correct.
After group presentations
After hearing from other groups' ideas, can our solution be improved?
Is there any feedback we received to improve our solution?
Was our solution clearly explained?
After mathematical modeling
What mathematics did my group use in our solution?
How well did I understand the mathematics that was used?
How well did I do working in the group?

(Stohlmann, 2017)

6. Effective prototype: MEAs are developed around "big ideas" in mathematics. This enables teachers to use MEAs as a formative assessment at the start of a new chapter and/or as a summative assessment to assess students' mathematical understandings.

MEAs are implemented starting with an opening article or video, then readiness questions to help students become familiar with the real-world context and the problem statement. Next students work in groups to solve the problem. They then present their ideas to the whole class. Finally, in their small groups they are given time for revision of their models and for reflection.

Through working with middle school teachers and students (Maiorca & Stohlmann, 2016; Stohlmann, Maiorca, & Olson, 2015) I have developed messages or questions to emphasize with students during the different parts of the implementation of mathematical modeling (**Table 1**). These ideas were emphasized and discussed with the middle school students in this study as they worked on the MEA.

Mathematical Modeling with Middle School Students

Middle school students can successfully participate in mathematical modeling activities and their abilities in mathematical modeling increase over time. In a study that used the Big Foot MEA with average ability middle school students, students progressed through stages of proportional reasoning development that have been observed over periods of several years (Lesh & Doerr, 2003). Other studies done with average ability middle school students and MEAs have demonstrated that groups develop complex mathematical models that integrate multiple mathematics concepts (Lesh & Carmona, 2003; McClain, 2003). This has been found to be the case as well with students in lower track mathematics classes once they have had prior experience with MEAs (Harel & Lesh, 2003). In an experimental study, using a sequence of six MEAs over 3 months Mousoulides, Christou, & Sriraman (2008) found that the experimental MEA group outperformed the control group on a modellng abilities test and the treatment was most effective for students with lower modeling abilities. Further studies have shown that middle school students successfully complete MEAs and use robust mathematical knowledge (Doerr & English, 2003; Mousoulides, Pittalis, Christou, & Sriraman, 2010).

While the research has shown that middle school students can successfully develop models, there are some groups that struggle with mathematical modeling. In completing the Natural Gas MEA, in which students are given data on annual average consumption for 15 years and have to predict when reserves will run out, four out of six groups of 12-year-old students developed models appropriate for solving the problem. Two groups failed to understand the concept of average and effectively use it in their models (Mousoulides & English, 2011). In a study done with average ability 7th graders who were doing mathematical modeling for the first time, about half of the groups had an acceptable model. The students completed the Historic Hotels MEA in which groups had to decide the best way to price a hotel room to maximize profit. All students understood the context and what the problem was asking and were able to use a systematic way to check profit from room price (Aliprantis & Carmona, 2003). Other difficulties that middle school students have had with mathematical modeling include 6th graders' discussions not refining their models (Mousoulides et al., 2007), 7th to 9th graders having difficulty choosing the most important variables and assumptions (Gould & Wasserman, 2014), and several studies have found that if students lack needed mathematics knowledge it could cause a blockage (Galbraith & Stillman, 2006; Ng, 2011; Stillman, Brown, & Galbraith, 2010). Galbraith & Stillman (2006) have also developed a framework for student blockages between six modeling steps with thirty-one general possible blockages. For example, a few of the possible blockages include being able to make relevant assumptions and clarifying the context of the problem. Connected to the possible blockages Stillman (2011) identified five metacognitive responses that students could have when faced with difficulties with four of these responses leading to unproductive results. The fifth response, routine metacognitive activity, allows students to self-assess the situation and make a productive decision in the process of creating their model.

In total, there have been positive results with middle school students and MEAs; though there is a need for more MEAs and mathematical modeling curriculum to be developed, implemented, and assessed. Though students may have some difficulties in working on mathematical modeling, their group members and other groups in the class can mitigate these difficulties to ensure that successful models can be developed.

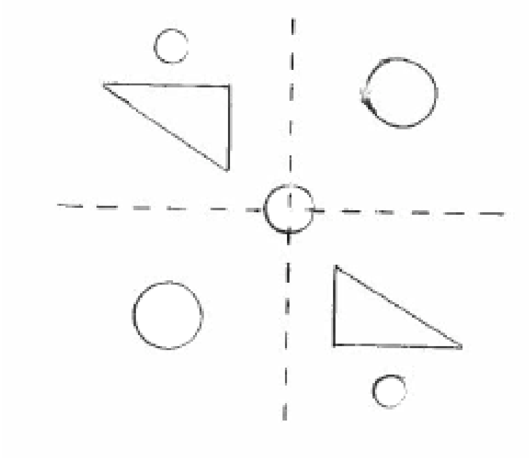
METHODS

This study was conducted with 16 middle school students (age 11-13) that voluntarily enrolled in a Saturday STEM program at a large research university in the Southwestern part of the United States. The students were from a large urban school district. The purpose of the Saturday STEM program was to provide a series of inquiry experiences designed to provide interesting and exciting opportunities in STEM education. The program lasted five Saturdays and the results from this study are taken from the second Saturday of the program. The students did not have prior experience with mathematical modeling before participating in this program. On the first Saturday of the program, the students completed the Big Foot MEA in which students must determine the height of a person given footprints and stride length (Lesh & Doerr, 2003).

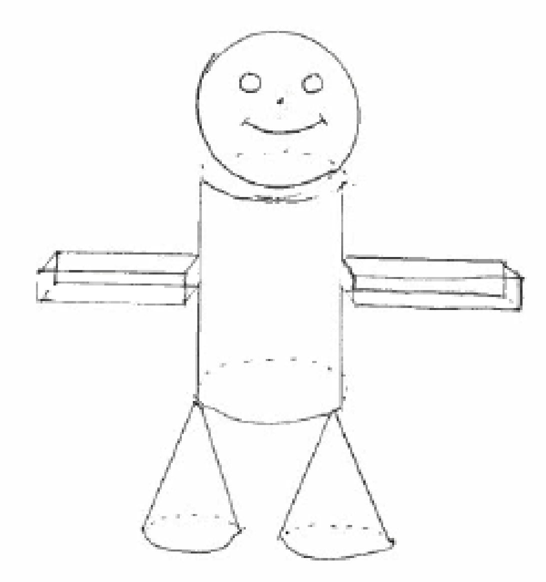
The MEA used in this study was the Robot Art MEA (See Appendix). The MEA has an opening reading that discusses how an artist, Max Chandler, uses robots and mathematics to create his art. Next, students answer readiness questions based on the reading and to think about how robots can improve our lives. The problem statement for this MEA is given to the students by a client, the high school robotics team. They would like to have a robot be able to be given directions to recreate any picture. Students are given sample pictures to choose from to test out how to best give directions to a robot. One student in each group pretended to be the robot. They listened to the commands given to them by two other group members and did exactly as told. They used a pencil to draw based on the commands given. The fourth member of the group kept track of the commands in order to develop the group's model for what instructions a robot would need to be programmed with to draw any picture.

Four pictures were provided to each group to develop their models and to practice giving commands to their robot. Students were given access to various materials if they wanted to use them including protractors, graph paper, compasses, computers, and rulers. **Figure 1** shows the four pictures along with what mathematics I thought students might use in giving directions to draw the pictures including the use of mathematical vocabulary. Students were able to pick which of the four pictures that they would use and were encouraged to try at least two of the pictures.

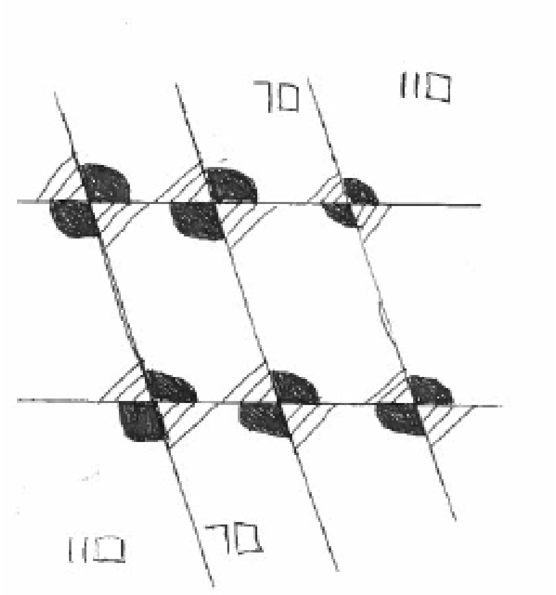
The data that was collected included audio recordings of each group and students' written work. There were four groups of students. The data was analyzed by writing a narrative of each group's model that was developed (Patton, 2001). Also, the data was coded for what mathematics the students used as they developed their models and in their final models. This was guided by a framework that I developed when I designed the MEA for what mathematics students might use.



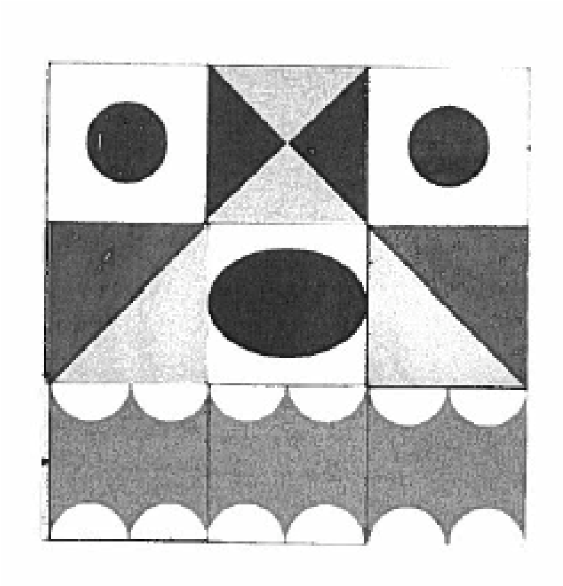
Picture 1: Possible mathematics
-Symmetry
-Shapes including right triangles
-Quadrants
-Coordinate plane
-Congruent
-Rotation
-Reflection
-Compass usage including radius
-Measurement



Picture 2: Possible mathematics
-Circle
-Point
-3-dimensional figure
-Right rectangular prism
-Congruent
-Cone
-Cylinder
-Compass usage including radius
-Measurement



Picture 3: Possible mathematics
-Parallel lines
-Supplementary angles
-Vertical angles
-Measuring and drawing angles with a protractor
-Measurement
-Congruent



Picture 4: Possible mathematics
-Shapes including right triangles
-1/2 of a shape
-Measurement
-Symmetry
-Compass usage including radius
-Congruent

Figure 1. Sample pictures along with possible mathematics students could use

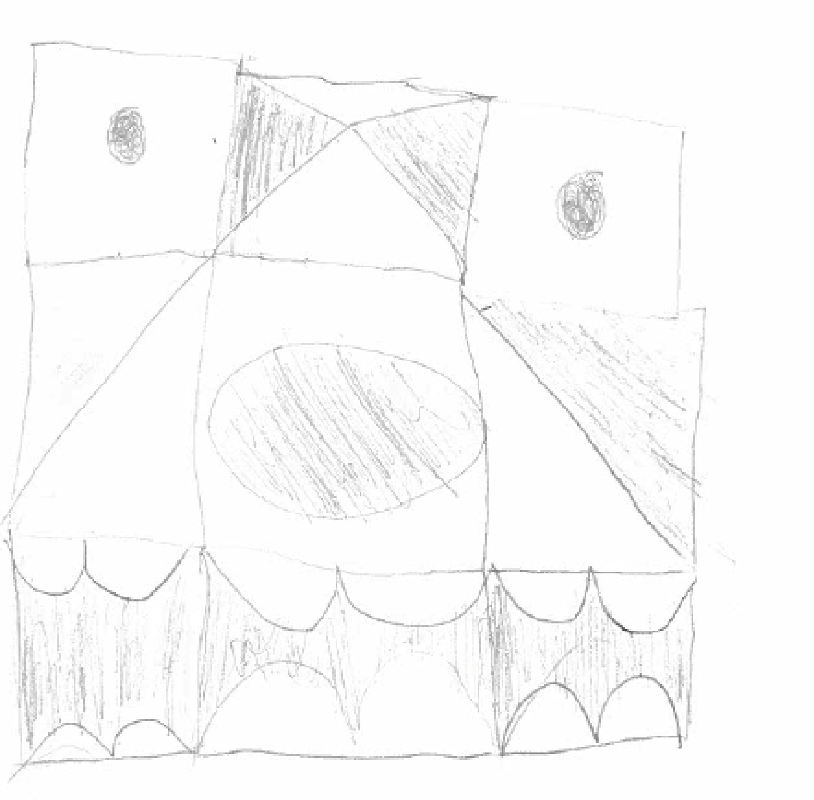


Figure 2. Group 1's created picture

RESULTS

Each group's development of their ideas will be described along with the mathematics that was used. At the beginning of each group's description I summarize the commands that the recorder for each group wrote down.

Group 1

Group 1 ended up using directions—up, down, left, right—, a stop command, an erase command, shapes, shading, a loop command, measurement lengths, and a placement command for where the robot was to begin drawing. They were able to have time to just attempt picture 4. Their final product is shown in **Figure 2**.

They had trouble getting started at first and found giving clear directions was difficult. The student that was the robot several times had to question the direction givers or give them feedback on what they could improve on. For example, "*You have to tell me when to stop." "How far up? Which way?" "You have to give me inches. How far right? How far to the left?"*

Initially the direction givers had the robot draw shapes that were in the picture, but did not tell the robot how big to make the shapes or what type of triangle to draw. *"One inch above the oval make a triangle."* Later on, they used general terms such as small, medium, and large for shapes. The direction givers attempted to use measurement lengths as a way to position the objects for the robot, but ended up using lengths only a couple of times. The robot was supposed to just follow the directions given or do nothing if they were not clear. The student that was the robot told the other students what he thought a better way to do this was. *"Just tell me to draw a line and then tell me when to stop."* The direction givers switched to this method and also ended up pointing on the paper where the robot was to start drawing. They used directions and a stop command for the robot to draw. *"Go down. Stop. Go to the left and stop."* Even with this method, the direction givers found they needed to have the robot erase several times because they did not say stop soon enough or the directions for what to do were not clear. One example were the directions, *"Draw a line from this corner to this corner."* The robot drew past where the line was intended.

This group also used a shade command for where the robot was to shade as well as shapes including semi-circles for the bottom row of the picture. After getting the robot to draw the bottom left square of the picture, they then told the robot to repeat the same method for the bottom middle and bottom right square, similar to a loop or repeat command for a code sequence. While not using the terminology congruent, the students also told the robot to draw the same triangle to finish the part of the picture in the top row, middle square.

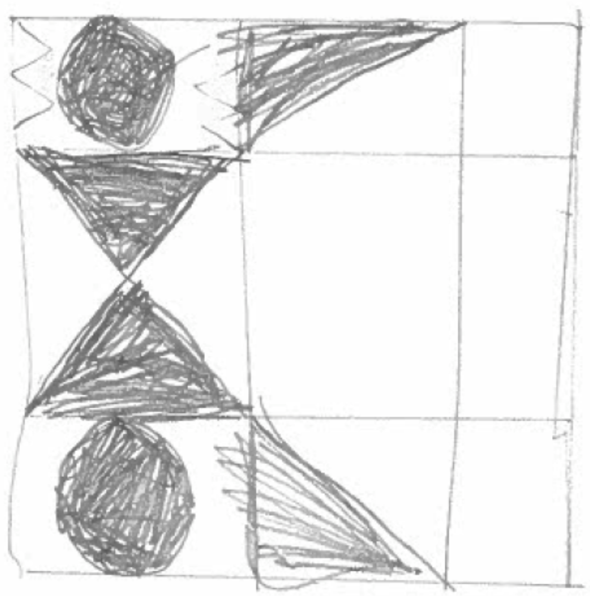


Figure 3. Group 2's created picture

Group 2

Group two used the following methods to tell their robot how to draw: measurement lengths, shapes, shading, a repeat command, and an erase command. They made use of multiple vocabulary terms including x-axis, y-axis, radius, origin, congruent, and diagonal. They used quadrants as well but did not use the term quadrant. For example, quadrant 2 on the coordinate plane was described as the negative, positive coordinate.

They selected picture 1 and also did the same picture as group 1, but used a different orientation for this picture. One of the group members took their robot's version of picture 1 with them so this picture cannot be shown but picture 2 is shown in **Figure 3**. They did not have time to finish the full picture.

Group 2 also had trouble with giving clear directions at first, but like group 1 found a method that worked. For picture 1 the direction givers had the robot draw an x-axis and a y-axis to begin. Next one of the direction givers said, *"draw a circle in the middle."* The recorder commented "*If just asked to draw a circle, a robot would not know where to draw or how big. Robots can't assume."* The direction givers tried to be more precise after this, but also kept in mind that the picture did not have to look exactly like the original. Because of this, this group also talked about small, medium, and large descriptions for their shapes at first. The direction giver said to make a small circle centered at the origin. For the rest of the circles, this group gave an exact length of the radius for the circles to be drawn. This group was clear on the type of triangles to draw in their picture in that they were right triangles.

For picture 4, the group started by getting nine squares drawn to set up the picture. They started with one square, giving the side lengths as 3 inches. They then told the robot to *"draw lines going down in the square an inch from each other. You will have three rectangles then in the square."* Similar to group 1 they also used a repeat command to fill in part of the picture with the top left similar to the bottom left.

One of the direction givers initially told the robot to make congruent triangles but changed his mind to a different method. He instead decided to use two diagonals. *"On the left middle square make a diagonal line just on the inside from the bottom left to the top right. Repeat the diagonal now on the bottom right to the top left."* This group also used a shade command. After hearing group 1's ideas they also stated they would use directions –left, right, up, and down.

Group 3

Group 3 used the following ideas in programming their robot: graph paper with numbering the lines, an erase command, and directions—left, right, up, and down. They also used the following vocabulary: square, circle, radius, diameter, cylinder, cone, diagonal, and triangle. This group had a difficult time in giving directions and communicating in general as a group. They also switched who was the robot so three of the group members were the robot for certain times. After starting with picture 4, the group quickly switched robots and then tried picture 2. They came back to picture 4 later with a new robot. Their final pictures are shown in **Figure 4**. It should be noted that since they switched who was the robot, the 2nd and 3rd robot was able to see the pictures ahead of time.

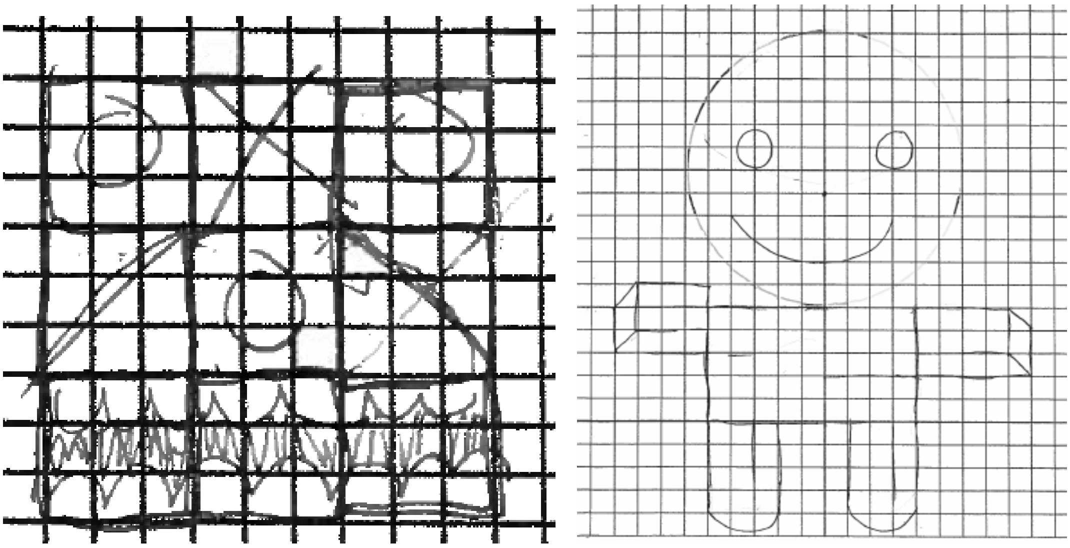


Figure 4. Group 3's created pictures

For picture 4, this group attempted to set up the picture first using nine, 3 x 3 squares. The direction givers attempted to have the first robot do this, but the robot did not know what to do. A direction giver stated, *"Draw a 3 x 3 square that is 9 units big."* The robot questioned the directions given: *"Be more descriptive. I don't know what a 9 unit square is…Yeah, but where should I put it?"* After this the group switched to picture 2.

The first robot then gave the directions, which started, *"Draw a circle."* The new robot then had several questions based on this: *"Where? How big? What's the radius? What's the diameter? What's the circumference?"* The direction givers then decided to number the lines on the graph paper so that they could count how far to the right and how far down to make the objects. For example, *"Go back to the 16th line and draw a line horizontal, then 2 units down and 4 units backwards."* They also at times told the robot to start and stop drawing once they got to the right starting position. They had some difficulties in getting the arms drawn on picture 2. One direction giver stated, *"Make the arms 4 units wide, next to the cylinder."* The other direction giver quickly noted, *"She cannot see the picture."* Another direction for this was to make the rectangle 3-dimensional, which the robot was able to know how to do.

When the group switched back to picture 4, they were able to set up their picture with nine 3 x 3 squares with the new robot understanding the directions to draw 3 x 3 squares. At one point one of the direction givers got frustrated when the robot was not drawing what she intended. The direction giver ended up taking the pencil and just drawing what she wanted. Group 3 was able to come up with a method that worked though, but struggled with giving clear communication. The group learned the importance of proper vocabulary and what is clear to oneself is not always clear to another person when communicating.

Group 4

Group 4 used the following ideas in drawing their picture: measurement, circles, right triangles, radius, quadrants, shade command, erase command, repeat command, and lines. Of all of the four groups they had the easiest time communicating and coming up with an efficient and clear method. This group started with picture 1 and ended up with a picture that looked almost exactly like that of picture 1. The direction givers had the robot make a dotted line down the center of the paper and then a dotted line through the center horizontally. After this the recorder mentioned that they could have just told the robot to make an x and y axis. This group used exact measurements for their circles in picture 1. For example, telling the robot to *"make a circle with a 1 inch radius in the center."*

They decided to label each of the four parts of picture 1 as quadrants. They did not use the conventional system for this but started in the top left as quadrant 1, then the top right as quadrant 2, then the bottom left as quadrant 3, and the bottom right as quadrant 4. They had a little trouble with drawing the right triangles when they used the direction, *"Now in quadrant 1 put an upside down right triangle."* The robot drew the right triangle in the wrong orientation so the direction givers had to ask the robot to erase. The direction of *"with a line on the right"* was good enough to have the correct orientation. The rest of the shapes were able to placed in the picture without any erasing.

The group then proceeded to do picture 4 without any erasing and with the robot only asking one clarifying question. For this picture one of the direction givers switched to being the robot because it seemed fun. The directions to the robot started with drawing a tic-tac-toe board. Then the group had the robot draw ½ circles and repeat this to fill in the bottom row of the picture. After this the group decided to label each of the squares as quadrants starting in the top left as quadrant 1, the top middle as quadrant 2, the top right as quadrant 3, the middle

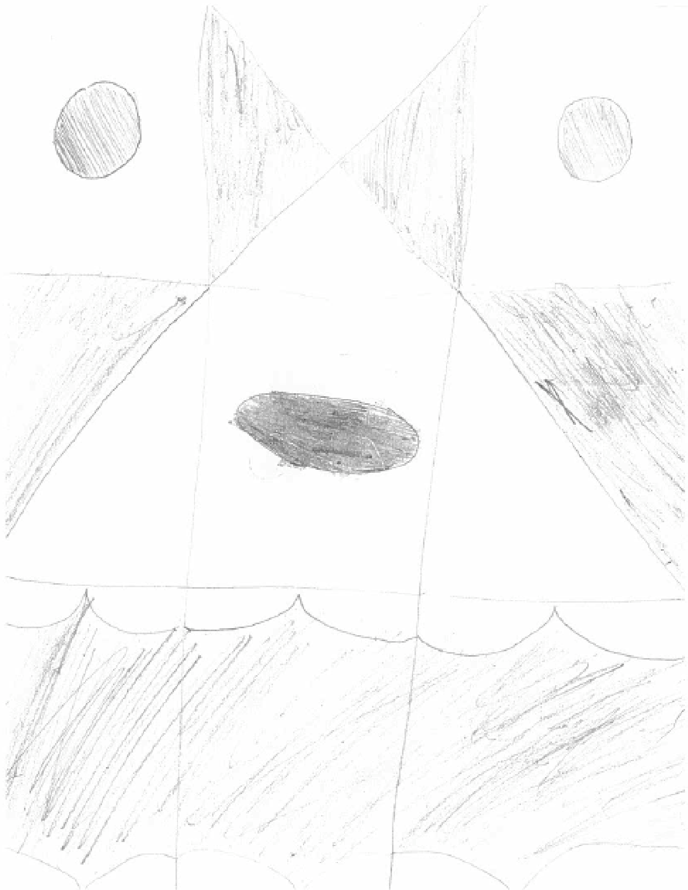


Figure 5. Group 4's created picture

left as quadrant 4 and continuing in this manner. One of the direction givers stated, *"In quadrant 1 make a circle."* The robot questioned, *"What is the radius?"* and was told 1-inch. One of the other methods this group used was to draw in line segments. For example, *"Make a line from the bottom right corner of quadrant 6 to the top left corner of quadrant 6."* They also had a shade command. For quadrant 2, to let the robot know which of the parts to shade, the direction givers divided up quadrant 2 into 4 quadrants to tell which of the two triangles out of the four that had been created to shade. **Figure 5** shows group 4's final picture.

DISCUSSION

This study was conducted to determine the mathematics that middle school students would use on the Robot Art Model-Eliciting Activity (MEA). The Robot Art MEA focused on the content of geometry and measurement and the students used measurement, various vocabulary, and commands connected to programming. Four groups of diverse urban middle school students were able to understand the difficulties on how to program a robot to recreate a picture.

When faced with difficulties, students were able to use routine metacognitive strategies (Stillman, 2011) to develop a method that would work. At times students had difficulties in communicating clearly but based on the structure of the activity students were able to self-assess the quality of their communication and work towards improvement. One of the benefits of mathematical modeling is that students can develop valuable 21st century competencies including communication and teamwork skills, that will help them in life and in any career.

This study shows that mathematical modeling can help to meet the aims and process standards that standards documents detail. One of the aims of the Australian Curriculum is "to ensure that students are confident, creative users and communicators of mathematics, able to investigate, represent and interpret situations in their personal and work lives and as active citizens" (Australian Curriculum, Assessment and Reporting Authority, 2017). This is echoed in the U.S. Common Core State Standards for Mathematics with the Standard for Mathematical Practice 6: Attend to precision. "Mathematically proficient students try to communicate precisely to others. They try to use clear definitions in discussion with others and in their own reasoning" (Common Core State Standards Initiative, 2010, p.7). In order for this to occur students need to have experiences in which they work in groups on realistic and engaging tasks that let students see how their mathematical knowledge can be applied.

While students were able to develop methods to recreate pictures, there are modifications that could be made to this activity. No group selected picture three which would require students to use more mathematics in their directions. The other pictures could be replaced with pictures that have been created using mathematics. Ebert (2014) writes about a graphing project where students used Desmos, an online graphing utility, to create an artistic design that uses parts of a number of different graphs. Using Desmos, students can make an artistic design employing points, lines, parabolas, hyperbolas, square root functions, circles, exponential functions, logarithmic functions, sine curves, and tangent curves. In Desmos, it is easy to restrict the domain and range of functions to help create part of a picture by using curly brackets (e.g. $y = 4x + 2 \{-4 < x < -2\}$). High school students were able to create cartoon characters and names among other things. The context of the Robot Art MEA could be changed to have the middle school students use Desmos to try to recreate pictures that high school students had created. While middle school students would not have knowledge of all the functions, pictures could be selected that would allow the middle school students to make use of lines, points, circles, and parabolas. Another option would be to have students use Geogebra.

The Robot Art MEA could be used as a possible lead in to work with actual robotics programming. Yuen et al. (2014) in working with elementary and middle school students in a summer robotics camp found that the students were engaged mostly in observing, discussing, and building over programming and planning. The Robot Art MEA can lead students to see the importance of holistic planning and well-chosen commands to lead to the desired results. Robotics has many possible benefits as students' interest in robotics continues to grow and can be used to teach science (Robinson, 2005), engineering (Barak & Zadok, 2007), and mathematics (Silk, Higashi, Shoop, & Schunn, 2010). Students' experiences with robotics can also increase their interest in STEM subjects (Grimes, 2012; Kim, Oh, Choi, & Tsourdos, 2014).

While students did not use all of the possible mathematics designed into the activity, teachers can use MEAs and mathematical modeling as formative assessment to build on students' understandings and further develop ideas that the teacher has in mind to pursue. Students as well learn from each other and assess each other's ideas during group work time and the groups' whole class presentation time. Such assessment provides a rich basis for identifying evolving mathematical understandings that can be further developed.

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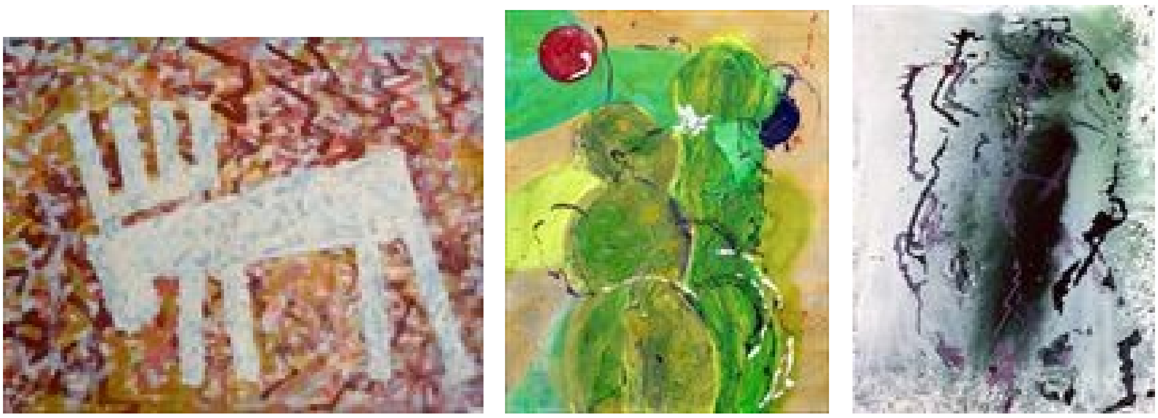
APPENDIX

Robot Art MEA

Max Chandler says that working with robots is the only way he can create the pictures he wants. Built from Lego bricks and aluminum, the robots look like miniature trucks and cranes. Some propel themselves on wheels, while others shuffle about on legs. Chandler's intention has always been to infuse his art with mathematics. An avid painter since childhood, he has loved math for almost as long: at nine, he was already writing computer programs. He went on to study math at MIT and has paid the bills working as a programmer. "I have always had this dual nature of being tied up in science and in art," he says. Simply rendering mathematical patterns on a computer and printing them out created boring and repetitive pictures. To get the shapes he wanted, he could program small robots to drag a paint brush or pen as they moved.

You might wonder if Chandler feels the end result is worth all the effort. His answer is a resounding yes. "It wouldn't be the same if it was just the robot or just me," he says. "Even if a viewer doesn't know why it is, the picture will look different." Whether the robots create something better than a human could is subjective, of course, but the pictures are unique. People say, "Wow, those lines are special -- how did you do that?"



Examples of Max Chandler's Robot Art

"Robot Art" Questions

1) How is Max Chandler's art different from a lot of other art?
2) Why does he use robots instead of a computer and printer?
3) What did Max Chandler study at college at MIT? How does he use this knowledge as an artist?
4) How can robots help to improve our lives?

Telling a Robot Artist How to Draw

For the National Robotics Challenge, there is a special competition to design and build an Art Robot. A team from the local high school has built a robot that can draw dots, lines, and common shapes like circles, arches, squares, triangles, ovals, trapezoids, and rectangles. The robot works great, but the team is having problems getting the robot to make "art" rather than just draw dots, lines, and shapes.

They think it would be cool to have the robot recreate a picture like those below by following spoken directions from someone. They plan to ask one of the judges to draw a picture and then one of the high school team members will tell the robot how to draw its own version of that picture.

The high school team is working hard on reprogramming the robot to accept spoken directions, but they need your help to know what directions they should say to the robot to make pictures like these. They have asked your team for help finding out how to tell a robot to draw its own version of a picture like the one below.

Your team has agreed to help the high school robotics team. Your team will make a set of instructions explaining how to tell a robot to draw a picture. The high school robotics team has given your team the following information to help you understand how a robot "thinks" and what they need from you:

1) One person on your team should be able to look at a picture and tell another person on your team how to draw a picture even though the person drawing has never seen the picture. There are sample pictures in the envelope provided so you can try this out in your group.
2) The person drawing the picture is pretending to be the robot; so, they have to follow directions exactly as they are given. If just asked to draw a circle, a robot would not know where to draw the circle or how big to make it. All instructions need to be very specific.
3) We want the robot to truly be an "artist" able to draw anything (like a picture made by a judge); so, we need instructions for how to tell the person drawing or robot about any picture not just one particular picture.
4) The new pictures need to look like the original picture but do not have to be exactly the same. Our robot is an artist with its own style.

Your team needs to make instructions describing what a robot should be told so that it draws a picture. Your team will present these instructions to the high school robotics team to help them understand what to do at their competition.

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The Links between Academic Research and Economic Development in Ethiopia: The Case of Addis Ababa University

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ABSTRACT

This paper aims to examine the major issues concerning the links between academic research and economic development in Ethiopia by considering the Addis Ababa University as a case. The paper is based on two premises. The first pertains to the idea that universities being one of the actors in knowledge production play central role in enhancing the economic development and competitiveness of a country through their missions of academic research and the formation of skilled human capital. The second concerns the argument that a strong collaborative link between Universities and the industry is crucial in enhancing scientific and technological innovation process and commercialization of academic research through technology transfer that is necessary for economic development. Based on a review of the conceptual and theoretical debates, documentary evidences and key informant interviews, the paper argues that the university-industry link/partnership in terms of academic research and innovation is not well developed in the Ethiopian context. The findings indicate that the contribution of academic research in enhancing the country's economic development is minimal at Addis Ababa University in particular and in the country in general. The barriers to the lack of strong link between university and industry in terms of academic research and innovation are discussed and documented. Finally, implications for a strong partnership among universities, industry and government in enhancing the contribution of academic research and innovation to the country's development are dawn.

Keywords: academic research, economic development, industry, innovation, knowledge, linkage/partnership, technology transfer, university

BACKGROUND

In today's world, sustainable development of a country depends to a larger extent on its ability to generate, adopt and apply knowledge. Knowledge and the knowhow to use the available knowledge have now become critical for a country's survival in the dynamic and competitive global environment. Universities have long been recognized as one of the important sources of essential knowledge and highly skilled labor across many countries. The increasing recognition of universities as key drivers for socio-economic development has re-shaped and transformed their traditional missions of teaching and research to adopt the goal of economic development as a third mission over the last two decades (Etzkowitz and Leydesdorff, 2000; Gunasekara, 2006; Arbo and Benneworth, 2007). Universities are expected to play fundamental role in accelerating the scientific and relevant technological innovations and thereby enhancing the economic vitality and competitiveness of a nation through their basic missions of generating and disseminating knowledge - from teaching and research (Geiger, 2006). In this regard, a collaborative link between universities and the industry is necessary for technology transfer and the commercialization of academic research. Notably, any technological innovation process implies close linkages among different players - the university, industry and government, and the nature and intensity of the interactions among these actors critically influence the innovative performance of institutions/enterprises within a given innovation system (Nelson; Lundvall and Johonson cited in Schiller and Diez, 2007).

The role of the University as a strategic resource is prominent feature that brings it to the inner circles of any national development agenda. Thus, countries at different or at extremely dissimilar stages of socio-economic and political environments as well as industrial and technological development have tried to use their universities for sustainable development. Ethiopia is not an exception in this regard.

In Ethiopia, the need to accelerate economic growth through human resource development, research and innovation is evident over the past decade. In the successive phases of the country's economic development plans and strategies, the role of universities in human resource capacity building and technological innovations has been identified as one of the key pillars in the economic and social transformation process of the country (see GTP I and II). Recently, the country's vision of being a middle-income country by 2020-2025 is the key driving force for investing on human capital and research-intensive activities. In this regard, universities play critical role in accelerating human development and technological capacity building and ensuring its sustainability. However, there increasing concern about what the universities are actually doing in terms of enhancing economic development through research and formation of human capital. Thus, necessitates for the present paper, which intends to examine what is actually happening in the Universities regarding the links between academic research and economic development. A thorough understanding of the links between university research and economic development in Ethiopia requires a detailed analysis of empirical data from different sources and using different techniques and the underlying assumptions of the entire systems related to economic growth, higher education and national innovation systems but that is beyond the scope of this paper. This paper addresses the following major questions.

1. How does Academic research influence economic development (conceptual issues)?
2. How do universities and industries interact in terms of research and innovation in the Ethiopian context?
3. Given the existing reality, what are the enablers or barriers for a positive link between university research and industry?
4. What can be done to strengthen the link/interaction between universities and industry?

CONCEPTUAL CONSIDERATIONS- ACADEMIC RESEARCH AND ECONOMIC DEVELOPMENT

Universities have been identified for their potential as key catalyst in the economic development and social transformation of a nation. Development in general and economic development in particular is a multidimensional and multifaceted concept that involves both growth and change.

Several economic and development theories, models and empirical studies confirm a strong relationship between Universities and socio-economic development (Katharina, 2000; Barro and Sala, 1995; Colgan and Young, 2005; Lundvall, 2007, etc). Geiger and Sa Creso (2005), for example, argue that knowledge creation and technological advancement are central to economic competitiveness. Scientific and technological innovation requires new knowledge (through research), human capital (through education), infrastructure (both physical and cyber), and new policies (intellectual property, anti-trust, tax), all of which depends both on public and private investment and upon the capacity of knowledge institutions such as research universities, corporate R&D, and national laboratories (Duderstadt, 2005).

The process of knowledge generation and subsequent use of it for development is at the core of new growth models. Endogenous growth theories stress the importance of innovation & technological change as a source of economic growth- a shift from material- and labor-intensive products and processes to knowledge-intensive products and services. In this perspective, innovation refers to the creation, diffusion and use of new ideas and technological advances in an economy, and can take the form of new products, new production processes, new markets and organizations (Yang, 2006). Research & development is a necessary condition for innovation-bears most directly on technological changes & thereby drive productivity.

The relationships between higher education institutions and the state, the institutions' traditional knowledge configuration and self-regulation practices as well as their external links have changed over the past years (Gibbons, 1994; Nowotny, Scott and Gibbons, 2003). Universities are expected to respond to the demands of the different stakeholders in their environment through working in partnership with the government and industry/business sectors. Such changing nature of role of Universities has resulted in the emergence of a 'triple helix' model that depicts the linkage between Universities, government and industry. As Etzkowitz, (2003) noted academic-industry-government relations are emerging from different institutional starting points in various parts of the world, but for the common purpose of stimulating knowledge-based economic development. These days, institutional arrangements that facilitate university-industry- government partnership are in place, and creating links with industry and government has already become one of the missions and mandates of Universities across many countries (the triple helix). There is, however, a major debate that a positive link between academic research & economic development is not always straight forward – it is a function of many complex and interrelated factors

In the triple helix model, the university is viewed as an archetype of innovation and research-central actor in new knowledge production, the industry epitomizes the users of the outcomes of university research while the government plays the central legal and policy role in speeding up and strengthening the linkage (Nwagwu, 2008). For such partnership to be successful, each actor should understand the other actor's needs and expectations. Hagen (2002) also argues that successful partnerships require a more sophisticated understanding of the complexities involved, the resources required and the adoption of a long term strategic approach if universities are to achieve the objectives of their new transformational role in economic regeneration. This then, is a call for change not only of universities surface structures but also deeper structures of values, beliefs and culture intrinsic to the traditional university role as well as commitment of the participating company to change (ibid).

The Rationale for University-Industry Linkage

The links between university and industry encourages the use of academic research by industries (Cohen, et al, 2002). It also enables both universities and industries to maximize capitalization of knowledge and technological innovations through knowledge spillover. The main reasons for enhancing university-industry linkage include the following (James, 2004):

- Universities provide a ready pool of graduate and undergraduate students that industry may access for their work requirements
- Technical opportunities exist in industry for faculty and students that may not exist in universities
- Materials/facilities exist in industry for research and educational purpose that may not exist in universities
- Collaborations with industry provide research funding to Universities
- Such collaborations can advance the service mission of Universities
- Collaborations provide for local and regional economic development.
- Universities often have research infrastructure that industry wants.
- Industry outsourcing to universities, to reduce the costs of doing business and increase profits.

Mechanisms to Facilitate Technology Transfer

The effect of University-Industry partnership on innovation & productivity of the economy may work through various channels. According to David, *et al* (2006), two principal mechanisms among others, facilitate the spillover of knowledge from universities to industries.

The first one involves academic/scientific research published in scholarly journals. Academic research is a key ingredient in the institutional identity of universities and an indispensable prerequisite for a successful program of teaching and public service (Weiler and Guri-Rosenblit, Sawyerr, 2008). Academic research is used here to refer to a scientific or scholarly inquiry undertaken by the academia of a given university on scholarly purpose. High quality faculty committed to research and teaching; high quality graduates who want to function with advanced expertise; an intellectual climate that encourages scholarship–an atmosphere of intellectual freedom in which teaching and research can be performed effectively; adequate and dependable research funding; research infrastructure, and high quality leadership are the essential characteristics of high quality research in universities (Bienenstock in Vessuri and Teichler, 2008).

The second type of spillover mechanism involves human capital embodied in students graduating from universities. The research capacity of universities and research and development centers of both public and private sectors to a great extent depends on the quality of human resource in the areas of science and technology (Vught, 2004). Thus, the extent to which universities are able to produce graduates with marketable skills and organize their research capacities for technological innovation and transfer has positive implication to the economic growth of a nation. The effect of University-Industry partnership on innovation and technological changes may also work through various channels viz., University and government research; research & development performed by industry/business; and foreign knowledge (knowledge generated in other countries) - through buying patents, licenses or know-how from foreign firms, observing competition (e.g. reverse engineering), hiring foreign scientists and engineers- internationalization, interacting with foreign competitors (foreign direct investment), reviewing the scientific and technological literature.

The university-industry interactions/partnerships also involve varieties of activities namely, staff exchange between Universities /research institution and industry; provision of training to industry professionals; endowments by industrial partners; research partnerships and services including collaborative, joint and contract research projects; shared research infrastructure (labs & equipment, business incubator and technology parks); academic entrepreneurship (start-ups, spin-off companies), and commercialization of IP (licensing patents).

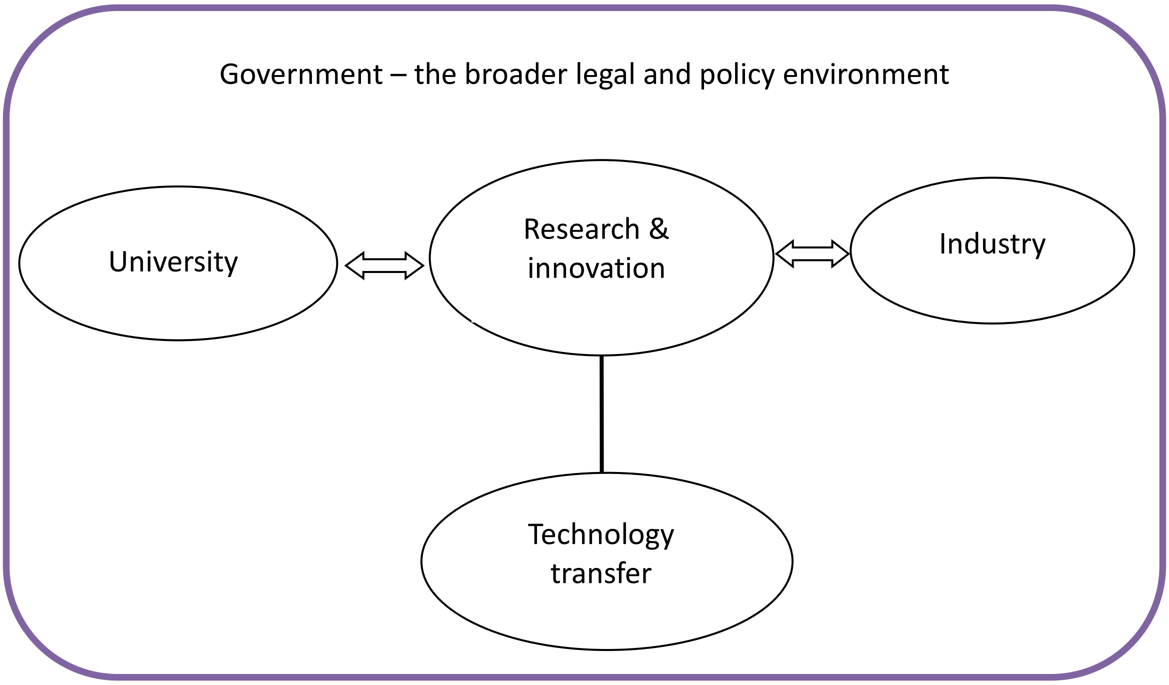

Figure 1. Conceptual framework: Links between academic research & economic development

Factors That Influence the University-Industry Linkage

The link between university research and economic development is subject to the influence of many factors. The major contributing factors include among others, University characteristics, industry characteristics and the legal and policy environment, which are briefly described as follows.

University characteristics: this refers to the factors that are internal to the university. These include the motivation and willingness of the University to engage in collaboration with industry in terms of research and innovation; availability of capable and engaged academic core, competent and committed leadership and adequate funding and research infrastructure to produce relevant and quality products (research outputs and graduates). Other factors include availability of policies and supportive internal governance system and procedures for research, innovation and technology transfer; networking and capacity for knowledge transfer to other actors; entrepreneurial mind set; and a research culture.

Industry characteristics: this refers to the factors that are external to the university. In this paper, industry is conceptualized in terms of all the manufacturing and non-manufacturing stakeholders influenced by the products of the University. The extent to which the industrial sector is developed matters a lot for a meaningful and strong partnership with the Universities. The major industry related factors influencing the linkage include readiness and motivation of the industrial sector to engage in partnership with university in terms of research, innovation and technology transfer; availability of adequate research and development infrastructure and personnel; investment(funding) in research and development activities; the absorptive capacity of the industry.

The legal and policy environment: this refers to the legislative and regulative aspects through which governments steer the behavior and operation of organizations in general and universities and the industry in particular. It includes policies, systems and regulatory bodies such as higher education policy and proclamation; Science, Technology and Innovation (STI) policy; national research priorities and strategies; rules and regulations; incentives including national government research funding, matching funds, seed money and tax exemptions; availability of technology parks and regulatory bodies for quality and relevance of education and research. Additionally, the broader political and socio-economic environment also influences the nature of the link/partnership among the three actors viz., the *University, Industry and Government.* For example, an affective research and innovation system requires support from both political leadership and public opinion; structural conditions; research ethics and values; capability of conducting research and dependable funding.

METHODS

In this study the link between academic researches and economic development is conceptualized in terms of indicators the number of contract and joint research projects by the universities and industries; Memorandum of understanding signed between universities on innovation & technology transfer, number of patents and commercialized research outputs.

This study employs mainly a descriptive survey method and some key informant interviews. The necessary data regarding the role of university research in economic development are collected through reviews of the existing legal and policy documents (mainly research, technology and innovation policies and strategies), proclamations, guidelines and working papers, national development plans, published reports and meeting notes. Additionally, an attempt has been made to capture theoretical and conceptual issues regarding university-industry linkage from internationally published and unpublished documents. Interviews have also been conducted with some key informants ((MoE, MoST, senior university leadership & academic staff, & industry). The key interviewees include 16 from Addis Ababa University (1 senior leadership, 5 middle level leadership, 10 academic staff), 1 each from the Ministry of Education & the Ministry of Science & Technology), and 3 from the industry. Due attention is given to identify key enablers or barriers for the positive link. The collected data are properly analyzed and interpreted. The Addis Ababa University is considered as one example to discuss some of the existing experiences regarding university- industry partnership in Ethiopia. The Addis Ababa University is selected based on its age and experience in teaching, research and community service as well as the comparative advantage of its location in the capital in terms of accessing the major business and manufacturing industries concerning teaching and research.

RESULTS AND DISCUSSIONS

This section presents the results of data analyses. The major findings are organized thematically as follows.

The Institutional Environment

Results of analyses of documentary evidences indicate that the vision of the country is the key driving force for investing on human capital and research-intensive activities for enhancing knowledge production capabilities of the country. As shown in the national development plans (GTP I and GTP II), a more knowledge-intensive approach to development is increasingly becoming the main route for bringing sustained and outward-oriented development and thereby bringing the country into a middle-income country by 2020-2025. Currently, there is a clear shift from the agricultural led to the industrial led-economy that demands for more quality graduates in the areas of science and engineering, and research & innovation activities. The universities' role in this regard is accelerating human development and technological capacity building and ensuring its sustainability. This suggests that the institutional environment for universities is changing in the Ethiopian context that demands universities to be responsive to the economic development o the country.

The Legal and Policy Frameworks

The Ethiopian government has introduced and implemented successive legal frameworks, plans and strategies within the framework of the 1994 education and training policy with the purpose to steer the behavior of higher education institutes. The main national legal and policy frameworks that directly or indirectly influence the link between universities and industry in terms of research and innovation are briefly discussed in the paragraphs that follow.

The 2009 Higher Education Proclamation (650/2009) - is the legal framework for the operation of the higher education system in Ethiopia. This law urges universities to define their core research areas and themes on the basis of the priority needs of the country, the institutions comparative advantages, and in consultation with the key stakeholders (Article 24, No. 2). The proclamation allows universities to conduct joint research projects with other national and international institutions, research centres, and industries (Article 24, No.3). In the proclamation, there is a clear focus on partnerships with industry in terms of research and technology transfer.

The National Science, Technology and Innovation (STI) Policy (MoST, 2016) - this policy, formulated in 2012, envisages the creation of a national framework that will define and support how the country will in future search for, select, adapt, and utilize appropriate and effective foreign technologies as well as addressing the establishment of national innovation system (FDRE, 2012). Research, technology transfer, human resource development, university-industry linkage and intellectual property systems are among the eleven critical policy issues considered in the STI policy directions and strategies. The policy establishes a national STI council and a forum for university-industry collaboration to regulate the national research and innovation priorities and systems.

The Research and Technology Transfer Conceptual and Governance Framework of Ethiopian Higher Learning Institutions (MoE, 2016) - is another new policy framework that defines vision, mission and objectives of research and technology transfer framework including opportunities and challenges. A framework regarding technology transfer, university-industry linkage and directions to strengthen research and technology transfer in the Ethiopian Universities are among the focus areas of this national framework.

Professional and Program Mix Policy (MoE, 2008) - The policy clearly articulates the 70:30 undergraduate professional mix in favor of science and technology over generally speaking humanities and social sciences. This policy has implications for stimulating university-industry partnership in terms of training and research.

Intellectual property (IP) rights system (MoE, 2008) - Intellectual property rights systems are considered as one of the essential mechanisms to enhance university-industry cooperation and commercialization of research and innovation. A review of the documentary evidences show that the issue of intellectual property rights policy is a recent phenomenon in the Ethiopian context, which traced back to establishment of the Ethiopian intellectual office in 2003. Since then attempts have been made to utilize the IP law as an instrument for technological innovation. However, results of the interview data show that the IP policy is not yet boiled down to the Universities. The major challenges gaps include absence of institutional IP policies in public higher education institutions, research and development organizations as well as public enterprises, and lack of awareness of the value and importance of IP protection is also mentioned as the problem among business enterprises.

The findings in the preceding paragraphs show that the national legal and policy frameworks recognize the role of science and technology for development, promote research & innovation that enhance knowledge & technology transfer, and require universities to engage in research including joint research projects with industry that serves the developmental needs of the country. However, the issues on how can university-industry partnerships be stimulated and enhanced in research and technology transfer activities are not well articulated. There is a weak synergy among the legal and policy frameworks in steering the behaviour of the industry and the universities towards meaningful collaboration in research, innovation and technology transfer.

Funding

Analysis of documentary evidences show that the government expenditure on education has been increasing over the past years, which is about 7% of GDP in recent years. Currently, education expenditure accounts for about 24.9% of the total public expenditure and the share of higher education budget from the total education budget has been reasonably high compared to the lower tiers of the education system (MoE, 2016). Public universities account for about 49.5% of the total education expenditure. However, funding for research and innovation from the government treasury is often insignificant or totally unavailable until 2012 because of soaring student enrolment that favoured allocations to teaching instead of research, and to undergraduate instead of postgraduate training (Fisseha, 2015). In 2011/12, the research budget of all universities accounted for only 1% of their total budget (MoE, 2015). Recently, 0.62% of the annual GDP is allocated for research, which is low compared to 3% in EU, 2.59% in US and other African countries such as South Africa.

The inadequacy of research funds has been hindering the research and innovation capacity of universities in terms of research infrastructure, facilities and equipment as reported by majority of the respondents. Analysis of documentary evidences and data from key informant interviews with university leaders and academic staff indicate that there are no intermediary funding agencies at national level that focus in stimulating university research and linkages with industries, business sectors and the community. The contribution of industry/business sector in funding university research is almost non-existent in the Ethiopian context.

Governance Structures for Science and Innovation

At national level, the Ministry of Science and Technology (MoST) has been established by proclamation No. 691/2010 as one of the most important regulatory bodies in the areas of science, technology and innovations. Preparing national science and technology research and development programmes based on the country's development priorities; coordinating science and technology development activities and national research programmes; and facilitating interaction and collaboration among government and private higher education and research institutions and industries with a view to ensure research and technological development are among the seven duties and responsibilities of the Ministry. Similarly, the government has also established national STI council and the national forum for university-industry linkage which are coordinated by MoST.

As one of its strategies to steer the behaviour of different actors, MoST has issued a Procedural Directive for the Linkage of Education and Training, Research Institutions and Industries in 2013. According to this directive, Universities are required to interact with industries in terms of ensuring the development of students' skills through practical trainings and to undertake need-based research that solves problems related to competitiveness of industry**.** To this end, many of the universities have opened university-industry linkage and technology transfer offices under the vice president for research and technology transfer to facilitate their interaction with industries in terms of training, research and innovation.

The Research and Technology Transfer Conceptual and Governance Framework of Ethiopian Higher Learning Institutions is another new policy framework developed by the Ministry of Education. It defines the vision, mission and objectives of research and technology transfer framework including opportunities and challenges in the universities. Under this framework, institutions will be supported through provision of funding for innovation, perhaps on a competitive basis. This shows the intention of the Ethiopian government to facilitate the science and innovation endeavors of the country.

However, results of the interview data from university leaders and staff shows that the national STI council and the national forum for university-industry linkage are not well functioning and their impact in enhancing the link between the industry and universities is minimal. Similarly, the university-industry linkage and technology transfer offices of the universities are not well developed to the level of attracting the industries through relevant and quality research and innovation activities.

Status of University and Industry Interactions in Terms of Research and Innovation

Results of analysis of documentary evidences and interview data indicate that the university-industry link was generally found to be at its beginning phase due to different reasons. Linking institutional research priorities with the priority need areas in the industry sector was marked by almost all interviewees as a new phenomenon in Ethiopia. The low level of industrialization in Ethiopia currently; shortage of capable researchers at universities (PhD holders accounts only for 11.3% of the total academic staff), and the poor attitude universities had traditionally towards the university-industry link and to its significance are the main challenges for building strong partnerships with industries.

The fact that universities are just starting working in consultation with industries and thus their experience of so doing is quite immature was explained by two factors. The first one was the fact that Ethiopia is just launching the scheme of industrialization very recently and they have never been many industries as such to work with. And the second one is the low level of awareness and experience by higher education institutions that industries play an extremely important place in the training of graduates and later in their deployment for work. One of the respondents from Addis Ababa University stressed that the development of linkage between the universities and industry in Ethiopia is an emerging one, a relationship that has yet started but started in a positive way. Given the low level of industrial expansion, inability to sort out needs and limited capacity to project markets on behalf of the industry and low level of awareness of universities to tie up their programs with industry, the link between universities' institutional research agenda and needs of industry and society is at a lower stage currently.

Interviews from the industrial sector on their part reported that the capacity of the universities in producing commercially attractive research and innovation outputs and graduates is one of the major challenges for strengthening their partnership with the universities. As one of the respondents from the industry reported, the industries prefer to import experts from abroad with fewer prices compared to the local universities to address their technical and knowledge constraints. This suggests that the readiness and willingness to engage in collaboration is yet to be developed in both the universities and the industrial sector.

Respondents from the Addis Ababa University, industries and Ministry of education witness that contract and joint research projects, commercialized research outputs, and patents are almost non-existent. As one of the interviews from the Addis Ababa University noted, there are only two international patents from universities in about 7-decade history of higher education in the country. Another respondent from the industry noted that though there are some memorandum of understanding between industries and universities (particularly with the old universities), the impact of the research outputs in terms of innovation and technology transfer are not emerged as intended. This shows that the link between academic research and economic development at national level is not well developed, though the issue is well articulated at policy level.

The Case of Addis Ababa University- The State of University-Industry Link

Addis Ababa University, as a pioneer higher education institution, has been playing its critical role in the formation of human capital in the country. It has been articulating research undertaking as one of its missions since its establishment in 1950. The movement to establish a link between the university's research and training to industry began to the 1980s that culminated with the formation of a University-Industry Cooperation Program in 1986 (see Daniel, 2008 and Fetene, 2014). The university has also made a similar attempt to establish a link with industry in 2000. However, all this attempts could not be translated into meaning action due to lack of adequate and coordinated efforts to stimulate a sustainable institutional linkage between the university and industry (Ibid.).

Engagement in mutually rewarding on-going collaboration with its stakeholders is still one of the missions of the Addis Ababa University. Recently, the university has put in place policies and thematic priority areas for research and offices to coordinate and lead research, university-industry linkage and technology transfer since 2010. There is also an increasing in fund allocation for research since 2012. Even though the overall scenario for collaboration and working with the industry appears to be limited, relative strengths were reported in the interviews conducted. Many respondents from the university explained that public universities especially the Addis Ababa University engage the public in setting out their institutional research agenda and in opening up new programmes. This is possible they underlined in the needs assessment academic programmes are required to carry out prior to designing new programmes of studies. Stakeholders from the public are invited to get engaged in the needs analysis process thereby articulating their needs and interests. The respondents also mentioned the opening of a director's office in Addis Ababa University to solely address the link between university and industry is an important step the university took to address the needs of the sector.

However, the role of academic research in terms of enhancing the productivity of the economic sector is generally dismal. Most of the research works undertaken by the academic and research institutions & PhD students are either shelved or presented in conferences or published in journals for the purpose of academic promotion. The research results are contributing in terms of ideas and policies, but do not reach the market in terms patents, commercialized research outputs and technologies for the industry. As one of the interviewees noted, no research results carried out by staff are changed into patents or technologies. For example, Addis Ababa University through its history gets only two patent internationally so far, as reported by the respondent. Hence the contribution of the Addis Ababa University in strengthening partnership with the private sector and enhancing the economic growth of the country through academic research and innovation is minimal.

Enablers for and barrier to a positive link between university research and industry

From the findings discussed in the preceding sections, the availability of governance structure at national and institutional levels; the existing policies science, technology and innovation and the current shift of the country towards industrialization may be considered as enablers or opportunities to strengthen the university-industry linkage in terms of research and innovation. However, the link between academic research and economic development is constrained by a multitude of factors. The major barriers for a positive link between universities and industries include.

- Lack of robust and overarching national framework that brings all actors (university, industry and government) on board to collaborate in research, innovation and technology transfer. The existing policy frameworks lack coherence and synergy to ensure strong partnership between industries and universities in terms of research and innovation.
- Lack of readiness and willingness on both the universities and industries to engage in meaningful partnership,
- Limited attention and inadequate funds for research & innovation at national level,
- Absence of well-established research infrastructure & facilities dedicated for research & innovation activities in both the industries and universities. The industrial sector is at an infantry stage and investment in research and development is yet to be developed in the sector,
- Inadequate institutional commitment and support at all levels,
- Shortage capacity/capable staff to undertake advanced research- Staff with PhD qualification accounts for only 11.3% of the total academic staff of the universities.

CONCLUDING REMARKS

This paper shows that the role of university research in economic development is vital. However, a positive link between university research and economic development is subject to the influence of many factors that are internal and external to the university. The findings indicate that University-industry partnership in terms of research, innovation and technology transfer is very weak in the Ethiopian context. Many of the enabling conditions are lacking. Particularly, the contribution of the Addis Ababa University in strengthening partnership with the private sector and enhancing the economic growth of the country through research and innovation is minimal. The role of the private sector in strengthening their partnership in terms research and development, innovation and technology transfer is yet to be developed. Thus, the university, private sector, and the government should take their share in creating strong linkages & partnerships necessary to enhance the economic growth of the country. This requires a robust national framework to enforce strong linkage among the three actors.

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