Design and Verify an Instrument of assessing Attitude toward STEM Teaching

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***Abstract*—**Since science, technology, engineering and mathematics (STEM) has been increasingly introduced in K-12 education, development of an instrument to measure teachers' beliefs in STEM has been needed. A STEM beliefs survey would be designed and verified for the purpose of this study. We used exploratory factor analyses to identify and confirm the factor structure of the STEM Beliefs Survey, and used Internal consistency reliabilities analysis for reliability evidence. The target population is middle school teachers in Taiwan. For the STEM beliefs instrument development, the validation samples for the study were 120 qualified middle school technology teachers. Internal consistency reliabilities on perceptions of science, math, engineering, technology, and STEM ranged from Alpha=0.629 to 0.982. The reliability of the instrument is from good to excellent according to the theory. Exploratory factor analyses were completed on the STEM Beliefs items. The instrument is benefit to plan teacher training or STEM courses for education authorities.

***Keywords*—**Assessing Instrument Development, Attitude toward STEM, STEM .

I. Introduction

TECHNOLOGY education is a subject area of common education and provides learner the opportunity of understanding technology. New technology grows everyday and the information and knowledge of technology expands, too. In science education, how to integrating emerging technology into formal education becomes a concern [1]. The education reform was implemented in Taiwan. Compulsory education was extended to twelve years and the 12-year basic education core curriculum had been finalized and announced in 2014. The Main Program of 12-year curriculum development is "core literacy", which is benefit to cohere the various stages of education and to integrate all areas or subjects [2]. STEM education plays a role in the education reform. Teachers' attitudes are crucial for the curriculum. There is a need to empower teachers to meet this reform tide.

Human behavior is affected by attitudes and beliefs affect attitudes. Attitude will affect teaching and learning and beliefs will affect the attitude. Students, lecturers, subject/syllabus and teaching facilities were related to each other and influenced each other on their contribution to successful teaching which could lead to successful learning [3]. Teachers' attitudes have received attention because of its direct relationship with students' learning. Since science, technology, engineering and mathematics (STEM) has been increasingly introduced in K-12 education, development of an instrument to measure teachers' beliefs in STEM has been needed.

This study focuses on the measurement properties of teachers' interests toward STEM. A STEM beliefs survey would be designed and verified for the purpose of this study .

II. Theoretical Framework

The term "STEM education" refers to teaching and learning in the fields of science, technology, engineering, and mathematics. STEMTEC [4] had addressed the needs of the future teachers who will teach science and mathematics at all grade levels. Science, mathematics, engineering, and technology are cultural achievements that reflect people's humanity, power the economy, and constitute fundamental aspects of our lives as citizens, workers, consumers, and parents. As a previous NRC [5] committee found:

> *The primary driver of the future economy and concomitant creation of jobs will be innovation, largely derived from advances in science and engineering. . . . 4 percent of the nation's workforce is composed of scientists and engineers; this group disproportionately creates jobs for the other 96 percent.*

There are increasing jobs require knowledge of STEM, not just for professional scientists.

In addition, individual and societal decisions increasingly require some understanding of STEM, from comprehending work procedures to evaluating competing claims about the environment to managing daily activities with a wide variety of computer-based applications.

Dugger, W.E. [6] presented STEM in USA as followings.

- STEM is the integration of Science, Technology, Engineering, and Mathematics into a trans-disciplinary subject in schools.
- STEM is a new offering in U.S. schools
- STEM education offers a chance for student to make sense of the world rather than learn isolated bits and pieces of phenomena.
- STEM can be taught in a number of ways (integrated subject matter vs. "silos" or other)

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● Science is the study of our natural world
● Technology is the modification of the natural world to meet to human wants and needs.
● Engineering is design under constraint
● Mathematics is the study of any patterns or relationships

The study of technology or Technology Education should NOT be confused with Information Technology, Educational Technology (Instructional Technology), or Information and Computer Technology (ICT)!

● National Assessment of Educational Progress (NAEP) [7], 2014 Technology and Engineering Literacy Framework is shown in Table 1:

■ Develop the recommended framework and specifications for NAEP Technology and Engineering Literacy Assessment in 2014 for grades 4, 8, and 12.

■ Recommend grade level(s) for the "probe" assessment in 2014.

■ Recommend important background variables associated with student achievement in Technology and Engineering Literacy that should be included in NAEP Assessment

■ The assessment will be entirely computer-based
● Some U.S. Efforts to Support STEM Education:
■ International Technology and Engineering Educators Association (ITEEA, WWW.ITEEA.ORG)
■ The National Academies (NAS, NAE, NRC, www.nap.edu)
■ National Science Foundation (NSF, www.nsf.gov)
■ American Society for Engineering Education (ASEE, www.asee.org)
■ Federal and State Efforts
● Some promises from STEM:
■ Enhance student learning in the subjects of critical need:*
■ STEM is an excellent way to synthesize and give more meaning to closely related subjects.
■ Students gain knowledge and abilities in an integrated environment.
■ Students are encouraged to be more innovative in what they are learning.
■ Students describe STEM as appealing and fulfilling
● Some challenges of STEM:
■ STEM requires systemic change by policy makers, administration, and teachers to set the agenda and make the transition:*
■ Change is difficult to make.
■ Many teachers were not prepared (nor want) to teach in an integrated environment.
■ The formal integration of subjects in the U. S. has not met with much success in the past.
■ May require additional resources.

Table 1 Major Assessment Areas in NAEP Assessment

Technology & Society	Design & Systems	Information & Communication Technology (ICT)
1. Interaction of Technology and Humans	1. Nature of Technology	1. Construction and Exchange of Ideas and Solutions
2. Effects of Technology on the Natural World	2. Engineering Design	2. Information Research
3. Effects of Technology on the World of Information and Knowledge	3. Systems Thinking	3. Investigation of Problems
4. Ethics, Equity and Responsibility	4. Maintenance and Troubleshooting	4. Acknowledgement of Ideas and Information
		5. Selection and Use of Digital Tools

Taiwan implemented education reform in 2014. The proposed core literacy of technology education structure from the twelve-year basic education curriculum is presented. In the figure 1, the core ability contained design, create, integrate, and communicate. On the lower right, the knowledge domain is composed with essential innovation, technological concepts, technological procedures, and impact evaluation. On the lower left side, the skill domain is composed with implement, use, maintain. On the button, the affection domain is composed with interests, attitudes, habits, and career explore.

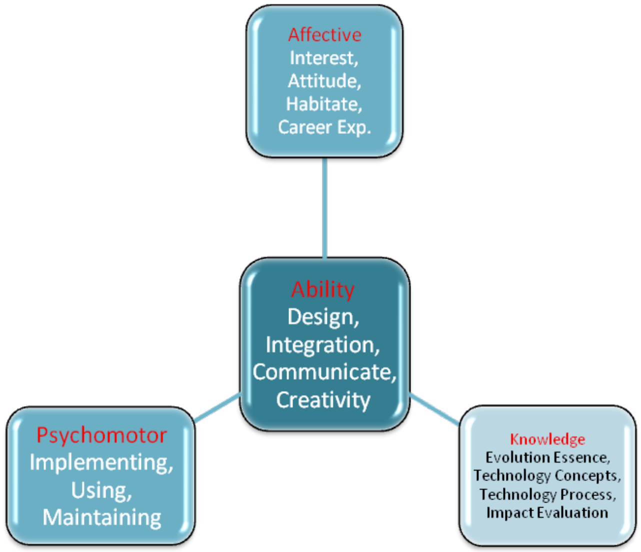

Fig.1 Core literacy Structure of Technology Education

In the conference document, several concepts were identified [8]:

- Technology is human design and making product.
- Technology education should provide students how to design appropriate product based upon needs.
- During design procedure, students should be required to think about the meaning of design product.
- During design procedure, students should learn system thinking through try and error
- During design procedure, students should learn applying science on what they design and make, so can fulfil daily needs and be innovating.
- For High-school technology education, the engineering design should be the core
- Engineering design should emphasis on applying STEM to learn how to think and explore design.
- Project based learning approach should be provided for students integrating STEM theory on practical problems, on extending technological creation on making innovated products.

A. Behavioral beliefs

Attitudes are important because they shape people's perceptions of the social and physical world and influence overt behaviors [9]. Behavioral beliefs involve the subjective probability that performing a behavior leads to a certain outcome. Three different processes underlie belief formation: first, behavioral, normative, and control beliefs can be established on the basis of direct observation (observational beliefs); second, they can be established by accepting information that is provided by an outside source (informational beliefs); finally, behavioral, normative, and control beliefs can be formed through a process of inference that relies on other beliefs relevant to the behavior under consideration (inferential beliefs) [10].

The theory of planned behavior (TPB) is a parsimonious model of behavior-specific cognitive determinants [11]. Central to the TPB is the idea that any behavior is determined by behavioral intentions, which are a function of three independent constructs: attitude, subjective norm, and perceived behavioral control. Attitude refers to the evaluative reactions of a person, favorable or unfavorable, towards engaging in the target behavior. In Fig. 2, TPB diagram was illustrated. Beliefs in behavior, norm, and control, are the basic components of the whole model. Attitude toward the behavior, subjective norm, and perceived behavioral control are contributing to intention of the certain behavior and the intention contributes behavior [12]

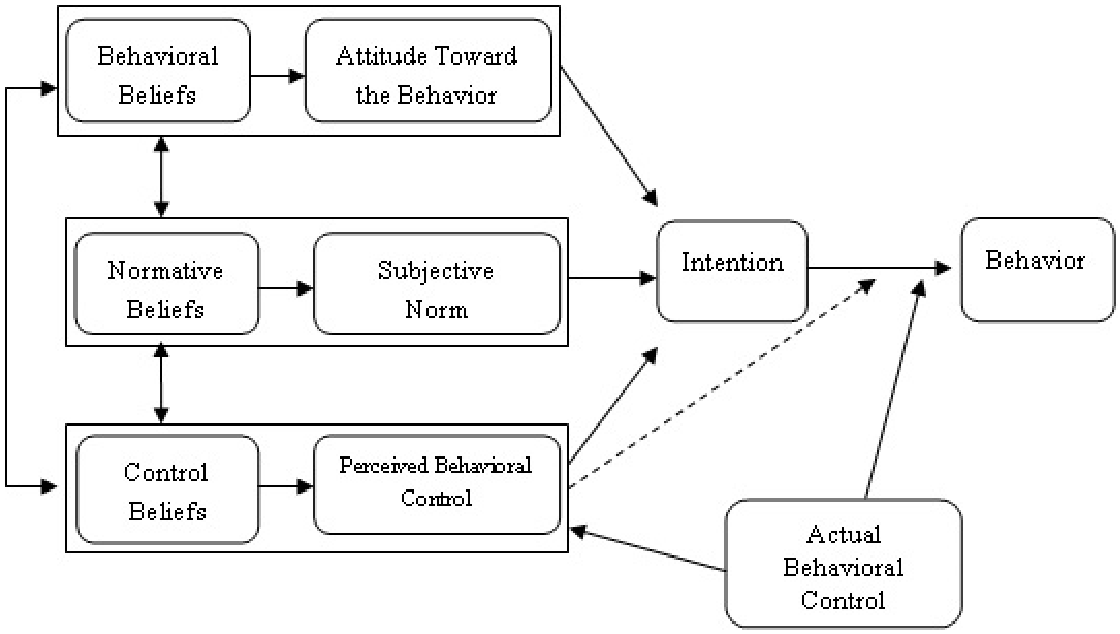

Fig. 2 TPB Model

B. Principle of STEM Education

K-12 science, technology, engineering and mathematics (STEM) education is important to a nation's economic health, yet schools and teachers are continually challenged to provide state-of-the-art STEM education [13]. Besides, Whereas United States President George W. Bush [14] announced the American Competitiveness Initiative [13]. This initiative was proposed to address shortfalls in federal government support of educational development and progress in the STEM fields at all academic levels which were under an increase in USA domestic higher education graduates within the STEM disciplines.

As Reddick, Jacobson, Linse, and Yong [15] mentioned, "Framework for Inclusive Teaching in STEM disciplines", which draws heavily from Banks' five principles, but extends and applies them to the context of STEM disciplines in higher education. This framework consists of five interrelated dimensions: Accurate Problem Definition, Iterative Design, Expert Practice, Management External Constraints, and Comprehensiveness. They should be treated well as:

- Clearly identify goals, rationales, starting conditions, appropriate design, and principles of implementation to achieve optimal learning outcomes.
- Recognize that an effective process is designed to adapt to changing conditions, monitor and respond to feedback, and provide alternate strategies when processes do not function as intended or other obstacles are encountered.
- Establish that your design and approach to teaching support effective learning of course content for all students.
- Anticipate, minimize, or compensate for ways in which teaching and learning processes and outcomes and influenced by environmental factors and other external constraints.
- Maintain thoroughness and rigor of what is taught, grounded in actual (rather than idealized) conditions.

Today's young people face a world of increasing global competition. We depend on the excellence of schools and universities to provide students with the ability to meet this challenge and to make their own contributions to nation's future. This larger context provides a rationale for setting this research.

Dr. Bement, A.L. in his testimony before the committee on Science U.S. House of Representatives stated that "NSF believes that Federal agencies must work in concert to ensure that every student has the opportunity to learn challenging science, technology, engineering and mathematics (STEM)". We believe that the investments in discovery, learning, and innovation have a longstanding record of boosting the nation's economic vitality and competitive strength [16]. He also suggested that "To maintain nation's pre-eminence in science and engineering, we must augment our Nation's research enterprise by fostering innovation in K-12 science and mathematics education". Sustained support will be critical to a comprehensive approach, including:

- Research on STEM learning for both teachers and students;
- Development of challenging STEM instructional materials;
- Assessment of student and teacher knowledge;
- Evaluation of project and program impacts; and
- Implementation of proven STEM interventions in the Nation's schools

When looking at research from the past 4 years in STEM education, the data in this paper suggests an even balance between academic research and action research for practitioners [17-25]. These findings are heavily influenced by an even selection of practitioner's journals and academic journals researched. There are practicing teachers interested in STEM education as a method of classroom instruction, which is evident by the numerous “small” research activities developed by teachers. Also, the teachers’ willingness to include other subject areas in their publications through integrated activities shows a desire to work across multiple disciplines. Clearly missing are large studies analyzing student performance and engagement in K-12 classrooms using integrated STEM instructional methods. There is a need to find ways to empower teachers with STEM education.

Rissanen [26] suggested that put technology as the major learning line and provide basic scientific education as an essential part of the general curriculum. Based upon elements of sustainable education strategy, active STEM education could be processed.

C. The Importance of Motivation and Interests in STEM Education

To increase student interest in STEM education, it is suggested that teachers should use informal learning, e.g., museums, STEM centres, after-school programs, seminars and workshops, and college outreach programs, to expand STEM beyond K-12 classrooms [27-29]. In their findings, learning motivation affects the amount of time that people are willing to devote to learning. Learners are more motivated when they can see the usefulness of what they are learning.

A statistically significant co-relationship has also been found between learners’ motivation and their learning performances [30]. Fang also suggested applying brainstorming as a creativity technique for idea generation and found that the effectiveness of “brainstorming with yo-yos” has been validated by 1) more than 50 physics concepts that student teams identified, and 2) highly positive student comments.

D.STEM certificate: a process model

Teachers play a critical role in exposing and encouraging students in STEM fields. To change the STEM for teacher education majors requires a revising” of STEM content courses and how they are taught at the undergraduate level. A number of reports charged STEM departments in higher education to take responsibility for developing college-level courses with appropriate content and pedagogy in the development of effective teachers [31]. There were four phases in Murphy and Mancini-Samuelson [32] study:

- Phase 1: STEM and education collaborative
- Phase 2: Alignment with standards
- Phase 3: Course design principles
- Phase 4: Implementation, assessment and sustainability

The STEM certificate is comprised of three interdisciplinary, team taught, lab-based courses. It is important that the certificate courses are open to all undergraduate majors at the institution [32]. Based upon their finding, it is noted that the curriculum standard could be followed to create the goals of STEM instruction.

E. STEM and Technology Education

The issue for technology education is that STEM is seen as an integration of science, technology, engineering, and mathematics education as one subject. This could have been an unplanned result of some outstanding curriculum projects generated by technology educators that did integrate one or more of these subjects [33] or of some technology teacher education programs where collaboration with mathematics and science educators in programs and departments took place, or the national standards for science, mathematics, and technology education incorporating integration and some overlap in standards.

None of those efforts were designed to transform the existing subject matter into an integrated substitute for the traditional subjects of STEM. Nor are the schools in any position to either add another subject or substitute STEM for the existing subjects while under the pressure of improving performance in mathematics and science.

Another issue is the misinterpretation of technology in the term STEM. Many people are interpreting this as instructional technology and computers, not technology education. Thus, they see the “T” as a tool to use with science and math content. Science and math are two silos that are dominating STEM efforts.

F. STEM Literacy

Breiner, Harkness, Johnson, and Koehler [29] suggested STEM literacy as followings:

- Ability to identify questions and problems in life situations
- Ability to explain the natural and designed world
- Ability to draw evidence-based conclusions about STEM-related issues.
- Understand human knowledge, inquiry, and design.
- Awareness of how STEM disciplines shape our material, intellectual, and cultural environments.
- Willingness to engage in STEM-related issues as a constructive, concerned, and reflective citizen.

They also defined a STEM educated student’s attributes:

- Problem-solvers
- Innovators
- Inventors
- Self-reliant
- Logical thinkers

They reported benefits of an integrated STEM approach to both student and teachers as followings.

Benefits to Students

- Develop self learning
- Transfer learning to other contexts
- Grow as critical thinkers and problem solvers
- Become engaged and purposeful in learning

Benefits to Teachers

- Become facilitators
- Use formative and summative assessments
- Use questioning techniques

● Teach technical communication skills
● Integrate STEM into many subjects and themes
● Match a variety of teaching and learning styles
● Develop new "stars" in the classroom

A STEM lesson should show attributes of Problem solving, Construction, Integration, Engineering Design process, Redesign, and Authentic learning [22]. The Engineering Design Process:

1. Ask: What's the problem? What have others done? What are constrains?
2. Imagine: What could be some solutions? Brainstorm ideas. Choose the best one.
3. Plan: Draw a diagram. Make a list of materials you'll need.
4. Create: Follow your plan and create it. Test it out.
5. Improve: Make your design even better. Test it out.

It is possible using the design process to guide the lesson.

● Ask – Students identify the problem by:
● Restating the problem
● Identify criteria (requirements) and constrains (limits) for the project
● Identify intended audience or client and method of presentation
● Imagine – Students investigate the problem by:
■ Asking questions
■ Doing research: how have others solved the problem?
■ Conducting investigations
■ Make preliminary sketched of a solution
● Plan – Students begin solving the problem by:
Choosing a final solution
Sketching the design
Gathering materials
● Create – Students build and test a solution by:
Checking the design against the criteria and constraints
Testing the design
Observing and collecting data on the design
● Improve – Students present and modify the solution by:
Presenting the solution to their audience
Receiving feedback on the design
Modifying the design based on the feedback

G.Measuring instruments

The *Mental* Measurements *Yearbook* is designed to assist professionals in selecting appropriate instrumentation in a broad range of social science areas. The series, initiated in 1938, purports to provide the most recent factual information, critical reviews, and comprehensive bibliographic references on the construction, use, and validity of all new and revised commercially published tests in English [36]. The Yearbook currently covers more than 4,000 commercially-available tests in categories such as personality characteristics, developmental level, behavioral assessment, neuropsychological characteristics, achievement, intelligence, aptitude, speech and hearing ability, and sensory motor skills. While almost all instruments focus exclusively on science, rather than the broader field of STEM, a search of *Mental Measurements* yielded one assessment, The Scientific Orientation Test [37] that would seem appropriate for ITEST projects such as MSOSW. The SORT, developed in Australia, was designed to measure attitudes toward several science-related topics for students in grades 7 through 12, and has been used for over 30 years in Australia. Rogers [38] expresses some concern with the use of the SORT for two reasons. In the intervening three decades since the test's inception, much has changed concerning science curriculum and attitudes towards science education, and Rogers suggests the instrument is in need of updating. In addition, although the test has been widely used in Australia, there has been limited use of the instrument in the United States.

Although the Mental Measurements Yearbook is a standard for researchers and practitioners in the field seeking to measure gain in academic areas, there are a few additional instruments that have been used by researchers interested in attitudes toward science and science achievement. One such instrument was developed by Novodovorsky [39] after a review of literature resulted in her conclusion that "many existing instruments are based on ill-defined theoretical constructs, and include statements that do not appear to be assessing the single construct of attitude toward science." After an item analysis, her initial 60 item scale was honed down to 20 items describing three factors:

1. Interest in science classes and activities in science classes
2. Confidence in the ability to perform science tasks
3. Interest in science-related activities outside of school.

The items were found to yield good reliability, but inadequate information was reported for the construct and criterion related validity of the instrument.

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Ornstein [40] used Novodvorsky's instrument to determine if the frequency of hands-on experimentation influenced student attitudes towards science. Although some gains were noted by the instrumentation, analysing the data by class did not reveal a significant difference between classes having and classes lacking hands-on laboratory activities. Ornstein indicates that her data may not show significance due to the small sample size. However, lack of validity and sensitivity of her instrumentation cannot be ruled out as a factor in the results she obtained.

As described here, none of the instruments reviewed meets the needs of identifying STEM teaching interests. Given the lack of updated, reliable, and valid instruments to measure STEM teaching interests, it is critical that instruments of this type be developed if we are to establish the effectiveness of STEM professional education on teachers, and through them on the students they teach.

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III. Method

A. Instrument Developmen

The STEM Beliefs Survey was adapted from Knezek and Christensen's Teacher's Attitudes toward Information Technology Questionnaire [41]. Their instrument was derived from earlier Semantic Differential research by Zaichkowsky. Studies using these instruments provided an idea of possible factor structures for the TESS. The Teachers' Attitudes Toward Information Technology Questionnaire gathers data on five separate indices from respondents. Semantic items are typically hand coded with a number from 1-7, representing the particular space the respondent marked between the adjective pairs, then keypunched by data entry staff.

For the first version of this STEM Beliefs Survey, there were five adjective pairs were incorporated as descriptors for target statements reflecting perceptions of science, technology, engineering, mathematics and STEM. Each of the 7 scales had five Semantic Perception adjective pairs. The first version of adjective pairs is in Table2. The STEM Beliefs Survey was finalized after reliability, and validity evaluation.

Table 2 The first version of adjective pairs

1.	Fascinating	1	2	3	4	5	6	7	Mundane
2.	Appealing	1	2	3	4	5	6	7	Unappealing
3.	Exciting	1	2	3	4	5	6	7	Unexciting
4.	Means a lot	1	2	3	4	5	6	7	Means nothing
5.	Interesting	1	2	3	4	5	6	7	Boring

B. Sample and Procedure

The target population is middle school teachers in Taiwan. For the instrument development, the validation samples for the study were 120 qualified middle school technology teachers.

C. Data Acquisition

Data were gathered from 120 middle school technology teachers on the focus for the STEM Beliefs instrument. The data was collected from the middle school teachers through an online data acquisition system.

D. Data Analysis

This study used both internal consistency reliabilities and Exploratory factor analyses to verify an Instrument of assessing Attitude toward STEM Teaching.

Internal consistency reliabilities on perceptions of science, math, engineering, technology, and STEM were used to determine whether the items are consistent with each other.

Exploratory factor analyses (Principal Components Extraction, Varimax Rotation, and Suppressed Display of Loadings < .05) were used on the STEM Beliefs items, using the data after internal consistency reliabilities analysis. This analysis was conducted in order to determine if the structures remained intact with five factors. The results of these analyses indicated that in every case the items loaded on the hypothesized factors. That is, the items targeted for assessing semantic perception of science, math, engineering, technology, and STEM were most strongly associated with the intended construct. These results can provide credible evidence toward re-affirming the conjectured structure and reconfirming the constructs derived from participants.

IV. Results

A. Internal consistency reliabilities

Internal consistency reliabilities on perceptions of science, math, engineering, technology, and STEM ranged from Alpha=0.629 to 0.982. The reliability of the instrument is from good to excellent according to the theory. Reliabilities for all scales are listed in Table 3.

Table 1 Internal Consistency Reliabilities for STEM Semantics Survey Scales

Scale	Number of Items	Alpha
Overall	15	0.908
Science	5	0.963
Technology	5	0.769
Engineering	5	0.642
Math	5	0.629
STEM	5	0.982

In the scree plot, there are five factors before the smooth portion. Factors in our instrument is five. The scree plot provides a support in Fig. 3.

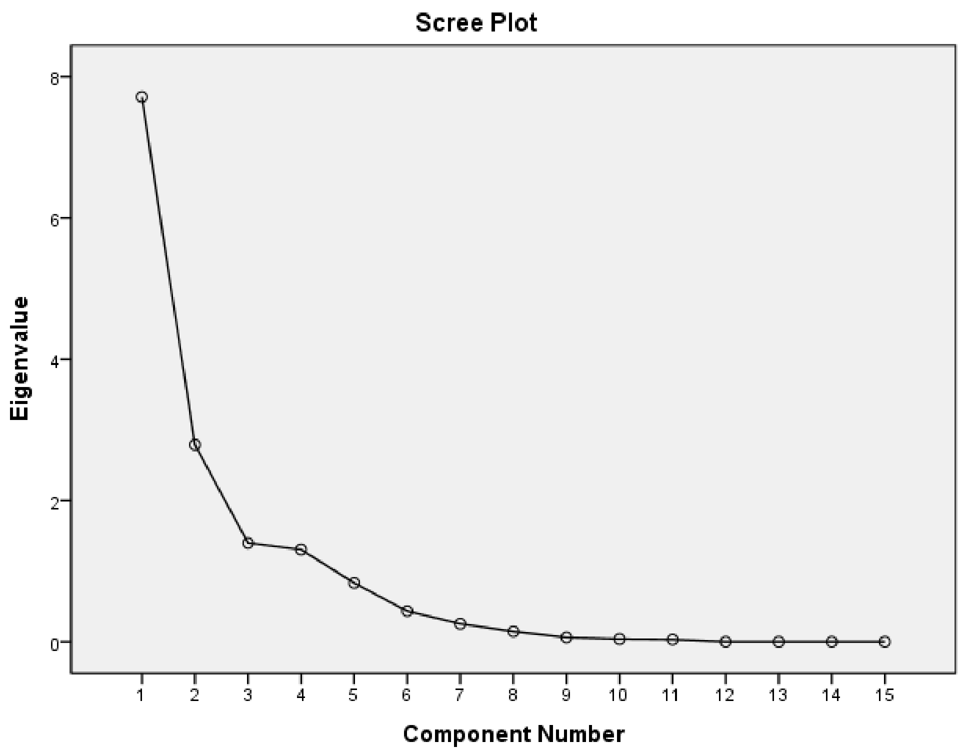

Fig. 3 Scree Plot of Factor Analysis

B. Exploratory Factor Analysis

This study used exploratory factor analyses to verify the constructs of the Instrument of assessing Attitude toward STEM Teaching. Using the available data, Exploratory factor analyses (Principal Components Extraction, Varimax Rotation, and Suppressed Display of Loadings < .05) were completed on the STEM Beliefs items.

In Table 3, five factors were requested to be extracted for the STEM Beliefs items. This analysis was conducted to determine the structures remained intact with five factors.

The results of these analyses demonstrated that the items targeted for assessing belief perception of science, math, engineering, technology, and STEM were most strongly associated with the intended construct in every case in Table 4.

These results provide credible evidence toward re-affirming the conjectured structure and reconfirming the constructs derived from participants.

Table 2 Principal Component Analysis of the instrument

Rotated Component Matrix[a]

	Component				
	1	2	3	4	5
ats1	.873				
ats4	.805				
ats5	.873				
att3			.425		
att4			.254		
att5			.869		
ate2					.917
ate3					.241
ate5					.094
atm1				.283	
atm4				.254	
atm5				.094	
ati3		.975			
ati4		.979			
ati5		.972			

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

V. Discussion and Conclusion

The purpose of the study was to design and verify an instrument of assessing attitude toward STEM teaching in order to provide an instrument to assessing middle school teachers' attitudes toward STEM teaching in Taiwan. First, we conducted a literature review and adapted from Knezek and Christensen's Teacher's Attitudes toward Information Technology Questionnaire. Then, we generated items to fit well with these constructs through a content and face validity process.

The STEM Beliefs Survey, using data from 120 middle school teachers, resulted in five factors (science, technology, engineering, math, and STEM) significantly indicated by 15 items. Internal consistency reliabilities on perceptions of science, math, engineering, technology, and STEM ranged from Alpha=0.629 to 0.982. The reliability of the instrument is from good to excellent according to the theory. The results of the exploratory factor analyses demonstrated that the items targeted for assessing belief perception of science, math, engineering, technology, and STEM were most strongly associated with the intended construct.

The instrument in this paper is short and available both online and in hard copy so that it is easy to implement in both formal and informal learning settings. The instrument has the capability of measuring teachers' changes in attitudes toward STEM in Taiwan. Instruments such as this would facilitate access to important information on the state of teacher participants' interests in and attitudes toward STEM, and how those interests and attitudes change over time. The instrument is benefit to plan teacher training or STEM courses for education authorities.

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