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Assessment and Evaluation of Non-Formal STEM Education Programs

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Abstract: This mini review is conducted to provide insight on assessment and evaluation of non-formal Science, Technology, Engineering, and Mathematics (STEM) education. The main guiding research question is how have assessment and evaluation of non-formal STEM education been conducted? Over nine studies were selected using the method of systematic review process. These nine studies were then analyzed. This mini review discovered that those studies have greater tendency to focus more on evaluation and summative assessment than formative one. Further action is proposed to address the need for use of more formative assessment to provide a holistic view on assessing non-formal STEM education programs.

Index terms: Non-formalSTEM education; evaluation; assessment

I. INTRODUCTION

Science, technology, engineering, and mathematics (STEM) education has been a huge part of education since as long as school institution exists. However, as the Fourth Industrial Revolution calls upon the heavy implementation of artificial intelligence technology, there has been an urge to produce sufficient workforce in related area. Integration of science, technology, engineering and mathematics has been identified as one of the keystone to the next industrial revolution. The increasingly complex society demand requires an individual to contribute by providing solutions that integrate the science, technology engineering and mathematics field. However, the lack of STEM workforce remains a threat worldwide. Malaysia has less than 3 percent workforce in the STEM sectors compared to 30 percent in developed countries such as Singapore, Japan, United State, and Germany .A recent study highlighted that the United States will need to fill 3.5 million STEM jobs by 2025, but as many as million vacancies will exist due to difficulty in finding people with the right skills. A recent study to investigate the correlation between STEM career knowledge and interest with likelihood of pursuing a STEM career among middle school students concluded that there is limited knowledge regarding STEM career hence declining interest in STEM careers [1].

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In order to increase students' positive behavior in STEM field, the non-formal education has been recognized as a supplement to the formal education received in school.Petnuchova (2012) defined non-formal education as learning process that occurs at the initiative of the individuals and a by-product of more organized activities, which may or may not have learning objectives. A visit to the museum, a summer technology camp, and Girl Scout are some of the examples of non-formal education. The non-formal education enables students to learn in more laid-back environment, more willingness and less structured compared to formal education received in school. These advantages provide high potential of meaningful learning experiences. Mohr-Schroeder et al. (2014) reported that students' STEM content and interest in choosing STEM fields for career showing positive increment after participating in non-formal STEM education's activity[2]-[8].

Despite the advantages offered by the non-formal education, the worthiness of this investment has been put on stake. The United States reportedly spent more than $3 billion per year on STEM education with 32 percent of this amount ($157 million) goes to non-formal STEM education. The report also claimed that the impact of non-formal STEM education is unclear due to the difficulty in defining measurable outcomes and assessing impact of these programs. The assessments and evaluation tools used are inadequate, hence making it hard to justify if the amount of money spent on non-formal STEM education is worth it[10]-[23].

II.Objective and Research Question

Non-formal education is a supplement to the formal education and is needed to increase students' positive attitude and content knowledge of STEM. However, in order to ensure the aims of the non-formal education are successfully achieved, quality evaluation and assessment need to be conducted.

This mini review iscarried out to answer the question 'how have evaluation and assessment of non-formal STEM education been conducted? The purpose of this mini review is to find similarities and patterns of how assessment and evaluation of non-formal STEM learning have been carried out.

III.METHODOLOGY

Articles regarding non-formal education were searched from various education journal database of Universiti Teknologi Malaysia's library portal: (1) Web of Science(2) Scopus (3) Wiley (4) Science Direct Journal and (5) Springer Link (6) Taylor and Francis (7) Academic Search Premier. Articles were also searched in Universal Journal of Educational Research and Google Scholar. Keywords used to extract these articles were: (1)Non-formal education (2) Informal Education (3) STEM education (4) Out-of-School Activity (5) Evaluation (6) Assessment and (7) Performance Indicator. The research articles searched were between the year 2008 to 2018.This timeframe was used in order see the current progress of this research topic that may provide some indications of studies done in the previous 10 years. Cronin, Ryan, and Coughlin (2008) pointed out that optimum time frame of 5 to 10 years should be used for article review. Over 50 articles were found, but only final 9were analyzed. The final 9 studies revolved on non-formal education conducted in the United States and Turkey.

Upon reducing to the final 9 articles,14 studies were initially selected. These 14 studies were chosen by reading the abstract and introduction of the studies. Studies with elements of Science, Technology, Engineering and Mathematics were kept. General non-formal education such as summer camp in general, visits to museums, and after-school were excluded. Non-formal education articles included come from integration and stand-alone of any of the Science, Technology, Engineering and Mathematics.

Only articles involving elementary and middle school student were included, and articles regarding pre-service teacher, tertiary education and early childhood were discarded. The age selection were made based on the fact that students form their attitude towards science between the ages of 10 to 14, a time when most receive little or no career education to support or manifest their ideas (Researching Science and Mathematics Education, 2013).Meanwhile, Tai, Liu, Maltese, and Fan (2006)reported that students demonstrating interest in science during age of 11 to 14 years old will be more likely to graduate in science compare to their peers who did not express interest in science. Hence, this mini review focuses on the non-formal STEM education given to elementary and middle school.

Articles with specific target on element, impact or effect of non-formal STEM education were also discarded. For example, a study investigating increment in content knowledge after non-formal STEM education (Newell, Zientek, Tharp, Vogt, & Moreno, 2015). This mini review looks into how assessment and evaluation of non-formal STEM education were conducted rather than linking any specific outcome with the non-formal education.

The types of non-formal activities were not limited to any specific time frame, race, gender, type of activities, student level of intervention, nor financial background of students' family. However, based on the non-formal education defined earlier, learning process that occurs at the initiative of the individual and a by-product of more organized activities, several more exclusions were done. Activities held under school curriculum such as science week and STEM ambassador visit were discarded. Students joined the non-formal activities should be on their own initiative. Activities with incentive given for attendance were also discarded to keep the student self-initiative factor pure. Non-organized or structured activities such as video games, reading activities were also discarded because they were not defined as non-formal that requires structure and organization.

The fourteen (14) articles were read thoroughly in order to recognize the purposes and methods of the studies. Studies with similar purpose of evaluating and assessing non-formal learning environment were kept for final analysis. There were 3 studies with purposes to assess specific activities in science center while 1 study was conducted to describe stages of developing assessment tool. These 4 studies were excluded from final analysis. Another one study excluded due to its purpose, which was to compare multiple non-formal provider in Turkey. The findings of final 9 studies are tabulated in Table 1 and Table 2.

IV.FINDING

Table 1 summarizes the authors, nature, purpose of non-formal STEM education, purpose of study, and primary findings.

Table 1 Authors, Nature and Purpose of Non-formal STEM Educations, Purpose and Finding of Studies

Authors	Nature of Non-formal STEM Education	Purpose of Non-formal STEM Education	Purpose of Study	Primary Finding
Birinci Konuret al. (2011)	Summer Science Camp in Turkey	To develop positive attitude towards science and nature	To evaluate the summer science camp	Increase in student attitude towards science and self-confidences towards science.
Metin & Leblebicioglu (2011)	Science Camp, Turkey	To introduce science among student using inquiry	To search the effectiveness of the science camp	Improvements in the children's conception of science.
(Mohr-Schroeder et al., 2014)	Summer STEM Camp, the United States	To expose middle-level students to a variety of STEM fields and STEM professionals through hands-on project-based learning experiences	To describe structure and activities of the summer STEM camp	Increase in student motivation and interest in STEM fields
Campbell et al. (2015)	Robotics Summer Camp, the United States	To build foundation skills needed in a college engineering program	To evaluate the effectiveness of the robotics summer camp	Increase in engineering technical knowledge and problem-solving skill
Hirsch et al., (2017)	Summer Science Camp, the United States	To introduce students to engineering, inform student about career in engineering and increase interest in STEM	To summarize evaluation process of the camp	Increase in STEM content knowledge, positive attitudes towards STEM, understanding in engineering design process
(Frye et al., 2016)	Engineering Summer Camp for Girls, the United States	To introduce more females into field of engineering through engineering based activity.	To discuss planning, implementation and evaluation of the camp	Increase in engineering understanding and analytical skill
(Kney et al., 2016)	Sustainability Engineering Camp, the United States	To expose students to critical environmental issues	To evaluate the camp and assessment method	Increase in student knowledge, awareness and concern of the environment
(Brown, 2017)	Science Field Camp at Ozark Natural Science Centre, the United States	To enhance the understanding, appreciation and stewardship of the Ozark natural environment	To assess the knowledge of students before and after camp and to evaluate the camp	Increase in knowledge of water quality and benthic Macroinvertebrates
(Leas et al., 2017)	After school STEM lessons, the United States	To enhance students' awareness and curiosity about STEM areas	To assess the impact of the after-school program on students	The after-school program encourage excitement in youth and motivation to pursue career in STEM

Besides, Table 2 summarizes the nature, frequency, measurement design, measurement tools and source of measurement tools.

Table 2 Nature, Frequency, Measurement Design, Measurement Tools and Source of Measurement Tools

Nature of Non-formal STEM Education	Frequency of Non-formal STEM Education	Measurement Design	Measurement Tools	Source of Measurement Tools
Summer Science Camp, Turkey	First time	Pre- and post-test	1. Science and Technology Course 2 Attitude Scale 3.Scientific Attitude Scale 4.Camp Evaluation Survey 5. Student interview	Adopted from Nuhoğlu (2008) and Moore and Foy (1997), customized tools
Science Camp. Turkey	First time	Pre- and post-test	1. Open ended questions from 'Views of the Nature of Science Version D (VNOS-D)' 2. Student Interview	Adopt from Lederman and Khishfe (2002)
Summer STEM Camp, the United States	Annually since 2010	Pre- and post-test, daily feedback	1. STEM Camp Survey 2. Content session feedback form 3. Parents feedback form	Customized tools
Robotics Summer Camp, the United States	Annually	Repeated measure test	1. Multiple choice assessment 2. Free response assessment	Customized tools with guidance given by the Accreditation Board of Engineering and Technology (ABET)
Summer Science Camp, the United States	Annually since 2007	Pre- and post-test	1. Middle School Attitudes to Mathematics, Science and Engineering (MATE). 2. Draw an Engineer Test (DET). 3. Student's logbook and final project	Adopt from Symington (1990), customized tools
Engineering Summer Camp for Girls, the United States	First time	Pre- and post-test	1. Students lab notebooks 2. The final essay and presentation, final summative survey 3. Pre- and post-test on effectiveness	Customized tools
Sustainability Engineering Camp, the United States	Similar concept program has been done in the past	Pre- and post-test	1. Self-design multiple choice 2. Open ended questions 3. Personal meaning maps	Customized tools
Science Field Camp at Ozark Natural Science Centre, the United States	Permanent activity in the science center	Pre- and post-test	1. Open ended questions 2.Observation during activities 3. Interview with parents	Customized tools
After school STEM lessons, the United States	Weekly or fortnight since 2012	Observations on selected sessions	1. Dimensions of Success (DOS) observation tool to evaluate the quality of STEM programs using objective measurements across a broad range of categories 2. Students' reactions during sessions	Adopt from Pear (2015)

I. DISCUSSION

Table 1 displays the purposes of all studies. It shows that 6 out of 9 studies aimed to evaluate the non-formal education while the other 3 aimed to assess. Assessment and evaluation are commonly used in a manner that they carry the same meaning. According to the Institute for Teaching, Learning, and Academic Leadership (University at Albany, 2006), assessment refers to"the process of objectively understanding the state or condition of a thing, by observation and measurement." As for evaluation, it refersto "the process of observing and measuring a thing for the purpose of judging it and of determining its value, either by comparison to similar things, or to a standard." Table 1indicates that most studieshad a greater tendency to focus on the outcome of a non-formal learning environment rather than getting feedback during the learning process. These studies were product-oriented rather than process-oriented, with the main aim to gauge quality rather than to improve the learning process.

Having a primary focus on evaluation is not a negativephenomenon. Saylor and Alexander (1974) emphasized the importance of evaluation by evaluating the evaluation process itself. However, in order to gain full benefit of non-formallearning environment, both assessment and evaluation need to be given equal attention. For example, an engineering camp evaluated as showing increase in students' technical knowledge in engineering and they are able to solve real-life type problem(Hirsch et al., 2017). By just judging the evaluation findings, conclusions were made based on the end result. End result provided may not reflect student's true achievement and potential.Students might not be at their best condition on the day of evaluation, hence showing low quality performance. While high quality performance may due to discussion among students. However,by taking into account assessment findings, student learning process can be observed. Hence, it can provide fair and absolute justification about the process.Rust (2002) called for assessment system that can tell whether or not a student meets learning outcome rather than assessing the module as a whole. This can be done by providing students feedback on their achievement of learning outcome and will ensure all program specifications are met.

Another explicit observation from Table 1 is the successfulness of these evaluations in providing finding that meet the main purpose of the non-formal learning. Oliva (1998) statedthat the primary purpose of curriculum evaluation is to determine whether the curriculum goals and objectives have been achieved. All these studies (in Table 1) have successfully determined that the non-formal education goals and objectives have been executed. Hence, itcan be concluded that all studies have met the primary purpose of evaluation. The ability of these studies to meet primary purpose of evaluation indicate that the assessment tools being used wereeffective and appropriate for the specific non-formal education individually.Macquarie University (2015)has stated that'an effective assessment isone which assesses students' attainment of the learning outcomes.' With unit learning outcomes are what students expected to know, understand or be able to do in order to be a successful in a field of study.

Table 2 shows measurement design conducted by all these studies weremostly delivered before and after the non-formal education to the students. This indicates that assessment in non-formal STEMeducation tended to be conducted in a summative manner rather than formative. Summarized from Rust (2002), summative assessment typically refers to the assessment of participants where the focus is on the outcome of a program. This contrasts with formative assessment, which summarizes the participants' development at a particular time. Another characteristic of summative assessment is it usually takes place after pupils have completed units of work or modules at the end of learning process. The goal of summative assessment itself is to evaluate student learning at the end of an instructional unit by comparing it against some standards or benchmarks. This is parallel with observation made previously which indicated that thesestudies have a greater tendency toevaluate rather than to assess. The perk of conducting summative assessment for non-formal STEM education is it gives direct output in terms of effectiveness of the program. Hence making it easy for public and government bodies to make decisions and a conclusion regarding the non-formal education conducted. Program evaluation as defined by Patton (2002, pp. 10)is a process that involves collecting and analyzing information about a program's activities, characteristics, and outcomes in a systematic manner. Its purpose is to make judgments about a program, to improve its effectiveness, and to inform programming decisions.

Also reflected in Table 2 is the frequency of the non-formal education. Most ofthe non-formal education was conducted periodically. The sustainability camp as a matter of fact using tools that have been revised in an iterative process. By having these studies providing evaluation of the non-formal STEM education, organizers can benefit from the finding and improve their program. Nevertheless, solely summative assessment is not the true measure of a learning process. Students' learning progress and ongoing feedback were not in the picture hence making it hard to determine whether students really achieved the expected outcome. By just depending on summative assessment, outcomes of the findings can still be questionable. Besides that, for a one-shot type of non-formal STEM education, by just depending on summative evaluation conducted at the end of the program, by the time evaluation was produced, nothing can be changed to improve the program. Rust (2002) concluded that summative assessments unable to provide information at the programs level and to make instructional adjustment and interventions during learning process. Hence, formative assessment is needed in parallel with summative assessment to provide a holistic view onnon-formal STEM education.

Table 2 also shows that each study possessed their own customized assessment tool. This is appropriate based on the difference nature of the non-formal STEM education. Nevertheless, these differences made them hard to provide a benchmark and standard measurement among all non-formal STEM education available.

Even though each non-formal education conducted with different settings and patterns, they were defined under one definition:learning process that occur at the initiative of the individual and a by-product of more organized activities, which may or may not has learning objectives. Hence, they still possessedsimilarities that can be measured. These similarities can be compared using a standard measurement tool and a standard effectiveness level can be determined. Feder & Wieman (2013), through their Committee of STEM progress report calls for the development of a standard evidence that all agencies could adopt in order to create common evaluation frameworks and tools that can be used by all projects.

Another finding from Table 2 is that all studies were conducted in a mixed method manner. Qualitative and quantitative methods were used together in order to perform the assessment and evaluation. Roberts and Povee (2014) suggested that a mixed method approach has higher content validity compared to any other methods when measuring attitude is the focus. In the point of view for non-formal education, the mixed method approach enables students' reaction and feeling to be explored in-depth alongside with the statistical quantitative measures. One example is the combination of personal meaning map and multiple-choice question used in the Sustainability Engineering Camp(Kney et al., 2016)This combination enabled assessment and evaluation to capture students' achievement and development of positive attitude spontaneously. In fact, this kind of methodology is appropriate in measuring all three domains of learning: affective, cognitive and psychomotor. Hence, all these studies have appropriately evaluated and assessed in a mixed method manner.

II. CONCLUSION AND IMPLICATION

To answer the research question of this mini research, 'howdid assessment and evaluation of non-formal STEM education were conducted?' four main conclusions can be drawn. This mini research found out that evaluation of non-formal STEM education was given more emphasis compare to assessment. In order to provide systematic and affectivenon-formal STEM education,evaluation and assessment conducted need to be able to reflect the non-formal STEM education thoroughly. Both evaluationand assessment of non-formal education can be conducted, rather than conducting only one of them. This is to provide not only its value and worthiness, but also the stage and progress of students' learning which can be provided from the assessment process.

The second conclusion is the non-formal STEM education tended to be assessed in a summative manner. As an implication, non-formal STEM educationshould be measured in total by both summative and formative manner. By doing so, apart from providing value and worthiness of the non-formal STEM education, in-depth feedback and learning curve can be collected. Hence it will be easier to make instructional adjustment and interventions on the non-formal STEM education.

The non-formal STEM education was evaluated and assessed using customized tools that fit best interest of its nature. It is about time that a standardized assessment tool to be created and implemented among non-formal STEM education. Rationale to this claim is to provide a standard measurement and a benchmark of how non-formal STEM should be conducted.

In conclusion, a mixed method approach in assessing and evaluating non-formal STEM education is the most appropriate method and the use of this method should be continued in non-formal STEM education programs.

III. LIMITATION AND FUTURE RESEARCH

This study lack on details of how customized assessment tools created. These details can reflect what criteria were taken into consideration upon creating assessment tools. These criteria could be analyzed and compared between all non-formal STEM education programs. Overlapping criteria could help to create a standardized tool that could be used forall non-formal STEM education programs.

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