Abstract
Rate of admission of students in science learning in institutions is increasing at a rapid rate particularly in senior secondary section, but the result of students’ achievement in learning science is not as per the level of expectation. In this context scientific aptitude (indicating the possibility of future success or failure of learners in science) of these learners has become a major concern of academic counselors and also researchers working in the field of science education. Scientific aptitude has also been selected as the focal theme of the present study. The study has been designed to explain the concept, to discuss psychometric construct of it – as viewed by different researchers. Among different discipline in science aptitude in physics has become the area drawing increasing attention of counselors and researchers. In view of this present study has emphasized on it particularly within the broad framework of scientific aptitude. Different operational dimensions of aptitude in physics have been referred in details. The related tools have also been reviewed critically. The review indicates extreme inadequacy in number of available related studies and thereby suggests the scope of further investigation of aptitude in physics. The study has its relevance to the researchers in operationalizing the construct psychometrically, to design the tools having sound psychometric basis in view of all these.

Keywords: Scientific Aptitude, Psychometric Construct, Tool, Aptitude in Physics

Introduction

Importance of science learning is being recognized more and more in the context of contemporary society which is highly scientific as well as technical. Effective science learning in this context is not only necessary for one’s individual development; it also helps learner to contribute significantly for the development of nation.

Science learning is not only important for the two reasons, as mentioned. In fact, it is also considered as a symbol of recognition of a learner in his/her surrounding environment i.e. school, home and society (Ganguli & Vashistha, 1991). Students feel a strong urge to enroll themselves in science courses particularly in senior secondary stage due to number of causes, among which to ensure their well acceptance in surroundings is also a major one. Parents are also driven strongly by this type of external motivation, considering science learning of their children as the symbol of social status (Shukla, 2005).

But mere enrolment in science course will not result benefit of learner in large extent unless students’ science learning is made effective also. There are several factors which influence science learning; among which their scientific aptitude is a major determiner. Scientific aptitude indicates the possibility of future success or failure in the area of science learning.
Therefore learners’ felt urge in learning science along with their sound scientific aptitude only may result in expected achievement (Ghosh, 1986).

But in the present system of school education at the time of admission in the various field of study in the higher secondary stage, students’ aptitude in that discipline is hardly recognized as the as the matter of consideration (DST, 2010). As a result, in spite of gradual increasing rate of enrolment of students in science courses, the scenario of students’ achievement in science is not as per the level of expectation. This failure in science learning increases the possibility of wastage of human resource and therefore has become a major concern of school teachers, administrators and also science educators (Ganguli & Vashistha, 1991; NAEP, 1979). Under this circumstance scientific aptitude of high secondary students particularly has become an issue of major concern (DST, 2010). This also leads to selection of the present topic.

Among various discipline in science, physics particularly is perceived by learners as an area of major difficulty. Its axiomatic nature, necessity of applying inductive-deductive, analytical-synthetic approach in its learning, particular nature of the curricular content consisting of several interrelated concepts having hierarchical nature etc. are the probable causes of this perception (Mukhopadhyay, 2011). All these may result in learners’ under achievement. Researchers have identified that student failure in science courses to a large extent is attributed to their failure in physics course particularly (Shukla, 2005). Therefore aptitude in physics of higher secondary learners is the area needs a major emphasis. Following questions arise in the mind of present researcher in this regard.

- How are scientific aptitude and aptitude in physics particularly explained and defined by researchers?
- What are various psychometric dimensions of these two?
- Whether available tool of these two are adequate and are constructed in view of all the essential psychometric considerations?

Present study is an attempt of finding answer of all these questions. It aims at particularly – to explain the conceptual frameworks of scientific aptitude, and aptitude in physics; to discuss various operational dimensions of these two as suggested by different researches, and to review the related tools in details. These are discussed step by step in the following sections.

**Conceptual Framework - Aptitude, Scientific Aptitude, Aptitude in Physics**

In the Dictionary of education (Good, 1959), aptitude is defined as “a pronounced innate capacity for or ability in a given line of endeavor such as particular art, school subject or vocation”. In this definition, an aptitude refers to an individual’s inborn potentialities or capacities which are indicative of some special abilities. ‘Aptitude’ in Great Illustrated Dictionary (in Rao, 1996) is considered as “a natural talent, skill or ability, quickness in learning and understanding”. In the above two definitions, it has been emphasized on that an aptitude refers to the capacity of an individual to be skilled in some work receiving formal and informal training.

Aptitude is not a specific skill; rather it is the capacity to acquire that specific skill (Freeman, 1965). If an individual has no aptitude for a particular type of work, he/she will not be skilled or proficient in that task in spite of training given to him/her. Whereas, right aptitude of a person, in any specific field, indicates his/her ability of acquiring skills in that particular field, on the basis of which a prediction may be made regarding the amount of improvement of that person in that field, which further training might effect (Rao, 1996).
Majority of the psychologists agree on the point that aptitude is innate, yet environmental factors on aptitude has also been recognized (Rao, 1996). As a matter of fact, aptitude is influenced by both biological and cultural factors of an individual.

“Scientific aptitude is a complex of interacting hereditary and environmental determinants producing predisposition or ability in science. Through these abilities, it is possible to predict future accomplishment of a person in science” defined by Rao, 1969. Researcher has also explained that scientific aptitude depends upon a variety of factors. Presence of certain study skills and persistence in learning science, motivation, satisfaction derived from learning science subjects, socio-economic factors and cultural background are some of the important determinants of scientific aptitude.

In the context of physics learning, explanation of the concept aptitude in physics, in particular is deemed necessary. Mukhopadhyay, 2011 has explained it as the ability of a learner in acquiring skill in selecting and making use of materials in physics properly for gathering information, processing those to develop knowledge and understanding towards different aspects in physics. This helps a learner in developing vocabulary, in recognizing a number sequence correctly, perceiving spatial relationship, relating variables by proper formulation, in understanding completely a given set of information, and functions of different devices etc. in physics and also in applying those in explaining and predicting various happenings following essential steps of a scientific method successfully in learning physics (which is acquired through proper physics education). This ultimately leads to prediction in learner’s future accomplishment in the area of learning physics.

Operational dimensions of Aptitude, Scientific Aptitude, and Aptitude in Physics – a brief review

Muchinsky, 2004 has identified the following primary mental abilities in relation to aptitude in any specific field. These are –
(a) General intelligence – general learning ability
(b) Verbal ability – vocabulary
(c) Numerical ability – mathematical reasoning in problem solving
(d) Spatial ability – ability to visualize and rotate objects in space involving figures.
(e) Memory – ability to recall or recognize after a brief exposure to words, symbols, numbers, and figures.
(f) Perceptual speed – ability to work quickly and accurately in scanning and perceiving similarities and differences in words, numbers, and pictures (mostly related with clerical aptitude).
(g) Psychomotor ability – ability to move hands and figures and co-ordinate their movement.

In relation to aptitude, particularly in science or science related domain, Muchinsky, 2004 also considered the ability – mechanical comprehension, the ability including information regarding use of tools and machines and also the application of reasoning to mechanical problem. Ramsay, Weison (as cited in Muchinsky, 2004) also recognized the importance of the ability of mechanical comprehension (mechanical aptitude) in measuring aptitude in technical or scientific disciplines, particularly in physics/mathematics. Nair, Ramanandan and Pillai in 1968 identified the abilities i.e. number series, information, formulation, spatial ability, verbal comprehension, and interpretation; in relation to scientific aptitude.
Sharma, 1980 considered scientific information, numerical ability, perception, reasoning ability, mechanical comprehension, space relation, and finger dexterity-in relation to the same. Gupta, 1985 found that these abilities could be grouped into three factors namely – (1) scientific reasoning (reasoning ability, space relation, numerical ability); (2) scientific achievement (scientific information, finger dexterity); and (3) perceptual scientific comprehension (mechanical comprehension, perception).

In relation to scientific aptitude, researchers have also considered the following abilities:-
1. Pandit, 1985: scientific knowledge, mathematical ability, mechanical aptitude, reasoning, and space relation.
4. Super (in Agarwal & Aurora, 1986) : describes- “Scientific aptitude being presumably largely an intellectual matter, it seems that battery of tests for the selection of promising scientists will stress such factors as reasoning, spatial visualization, number ability, science vocabulary and mechanical comprehension”.

Therefore the study revealed that a number of abilities might have their significant role to explain the construct of scientific aptitude, as each of them have been considered by different researchers in relation. These are mentioned as following:

b. Spatial ability: Nair et al., 1968; Sharma, 1980; Sharma (in Rao, 1996; Ruch et.al. (in Muchinsky, 2004).
c. Mechanical comprehension: Pandit, 1985; Sharma (in Rao, 1996); Ramsay (in Muchinsky, 2004), Weisen (in Muchinsky, 2004); Muchinsky, 2011.
d. Scientific vocabulary: Super [in 1].

Scholastic aptitude (in science) discussed so far, is found to be considered in relation to different primary mental abilities, which are cognitive by nature. Omotayo and Oladeya, 2008 considered cognitive and affective factors separately in relation to scientific aptitude instead of a single-construct aptitude (Cognitive and Affective Domain Aptitude Test: CADT, Omotayo and Oladeya, 2008).

In addition to cognitive factors, different non-cognitive factors i.e. Emotional intelligence, vocational interest, personality traits etc. have been considered in relation to the construct of Multiple Aptitude by Jackson (in Muchinsky, 2004). But single construct aptitude based on primary mental abilities is used widely by researchers, particularly in scholastic areas (Muchinsky, 2004).

Giri, 1976 has explained the construct of aptitude in physics in terms of the abilities namely-functional knowledge, conceptual understanding in physics, knowledge of nature and structure in physics, creative thinking in physics, and scientific attitude. Mukhopadhyay, 2011 has explained the same construct considering the abilities as- scientific information in physics, vocabulary in physics, number series, spatial ability, formulation, verbal comprehension and interpretation, and non-verbal (mechanical) interpretation. These are the primary mental abilities used widely by researches. Some among these are similar to the dimensions in terms of which Rao, 1996 explained the construct ‘scientific aptitude’.

Studies, so far discussed, showed extremely inadequate number of attempts to explain the construct of aptitude in physics, in particular. Physics has immense intellectual, utilitarian as well
as vocational value. For educational and vocational guidance, particularly for higher secondary students, this operationalization of aptitude in physics is essential; hence there is the scope of further study.

Review of the tools on Scientific Aptitude, and Aptitude in Physics

Following table (Table I) shows different Tests on Scientific Aptitude, and Aptitude in Physics indicating various psychometric details of these.

<table>
<thead>
<tr>
<th>Test</th>
<th>Sample</th>
<th>Sub-dimensions</th>
<th>Reliability</th>
<th>Validity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Scientific Aptitude Test Battery, (SATB: Sharma, 1980)</td>
<td>Secondary</td>
<td>Scientific information, Numerical ability Perception, Reasoning ability, Mechanical comprehension, Finger dexterity</td>
<td>Composite reliability (0.90)</td>
<td>1. Predictive with respect to scientific achievement 2. Factorial (Three factor construct, explaining 67% variance)</td>
</tr>
<tr>
<td>3. Kerala University Scientific Aptitude Test by Nair Ramalingom, Pillai; in Rao, 1996</td>
<td>Secondary</td>
<td>Number series, Scientific information, Formulation, Spatial ability, Verbal comprehension</td>
<td>Split-half (entire test, as well as for individual sub-dimensions) (r = 0.55 to 0.88, p&lt;0.01)</td>
<td>1. Internal validity (significant item-item, item-total correlation) 2. Predictive validity with respect to scientific achievement.</td>
</tr>
<tr>
<td>4. Scientific Aptitude Test: Pandit, 1985</td>
<td>Standard IX</td>
<td>Scientific knowledge, Mathematical ability, Reasoning, Mechanical aptitude, Space-relation</td>
<td>Specifically not found</td>
<td>High concurrent validity, measured with respect to a number of other standard test</td>
</tr>
<tr>
<td>5. Scientific Aptitude Test Battery standardized by Agarwal and Aurora, 1986</td>
<td>High School Students</td>
<td>Reasoning number, Scientific information, Vocabulary and Numerical ability</td>
<td>1. Test-retest 2. Split-half for individual sub-test as well as for the entire test,(r=0.84 to 0.93, p&lt;0.01)</td>
<td>Predictive validity, w.r.t school science, mathematics, total examination score (r=0.59,0.57 and 0.58; all significant</td>
</tr>
</tbody>
</table>
Review shows the following points:

1. Test on Aptitude in Physics suitable for higher secondary students is numbered, in particular.

2. Novel and the only one study is found in this regard. Giri, 1976 constructed and standardized a test on Aptitude in Physics for senior secondary students. Sub dimensions of the test are found critical, encouraging not only knowledge of fact and information of a student but at the same, clear understanding of various steps involved in exploring scientific knowledge in physics (i.e. the sub-dimension – Nature and Structure of Physics), thus emphasizing on both the product and the process aspect of knowledge.

3. The test of Giri, 1976 may have the problem of over generalization in selecting the sub-dimensions. The sub-dimensions i.e. Functional Knowledge, Conceptual Understanding etc. need to be made more specific, otherwise the corresponding items of those dimensions may not ensure their individual entity in the composite overall construct. Overgeneralization may be avoided by incorporating essential primary mental abilities and by expressing the sub-dimensions in specific and more measurable way, to ensure strong identity of the items at the individual level, which together might also lead to a common construct, which is the Aptitude in Physics. Items measuring those abilities should also emphasize on both the product and the process aspect of the knowledge in physics. Sen & Mukhopadhyay, 2008 has constructed one Test on Aptitude in Physics for secondary passed students. The test consists of seven different dimensions, as already mentioned in section 2 of the present study). The test was initially administered on 200 students, studying in class XI (science) in different institutions in West Bengal, India. This was the try-out sample, depending upon the responses of which items were analyzed. Later on, the test was standardized on the basis of the response of 703 numbers of students consisting of various components as per gender and habitat. Reliability of the test was estimated using KR-20 formula (in terms of internal consistency reliability coefficient), and also using split-half method. Reliability coefficients were determined for each of the selected sub-dimensions separately, and also for the entire test. Face validity (in terms of school teacher’s opinion towards appropriateness of the test for the students, and analyzing the opinion using chi-square testing), intrinsic validity (in terms of sub scale-sub scale, and sub-scale total correlation, content validity (in terms of experts’ opinion), predictive validity (in relation to students achievement in last board examination), concurrent validity (in terms of correlation of scores of this test and that of Scientific Aptitude Test by Nair et.al, 1978), and construct validity (using principal component of factor analysis) were estimated. Norm was established in terms of mean, standard deviation, percentile, and stanine. Table II shows the results of reliability and validity of the test in details.

<p>| Table II Results of reliability and validity of the test on Aptitude in Physics (Sen &amp; Mukhopadhyay, 2008) |
|--------------------------------------------------|--------------------------------------------------|
| Reliability                                      | Results                                          |
| 1. Split half (For each sub-dimension and for the entire test) | a. r, for different sub-dimension, ranging from 0.72 to 0.83 b. r for entire test 0.86 (all significant at 0.01 level) |
| 2. Internal consistency reliability using K.R.– 20 formula | r for different sub-dimensions ranging from 0.74 to 0.85. For entire test r=0.87. (p&lt;0.01, for all) |</p>
<table>
<thead>
<tr>
<th>Validity</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Face validity – school teachers’ opinion towards appropriateness of the items for the students.</td>
<td>Strongly in favor</td>
</tr>
<tr>
<td>2. Intrinsic validity (sub-scale – sub-scale, sub-scale – total correlation)</td>
<td>r varies from 0.141 to 0.699 (significant at 0.05 and 0.01 level)</td>
</tr>
<tr>
<td>3. Content validity (experts’ opinion)</td>
<td>Favorable</td>
</tr>
<tr>
<td>4. Predictive validity (in relation to score in science in last board examination)</td>
<td>r = 0.596 (significant), regression equation : y = 0.78x + 42.63, y = score on science (Standard Score), x = score on Aptitude in Physics, Standard Error = 2.78</td>
</tr>
<tr>
<td>5. Concurrent validity (using Scientific Aptitude Test standardized by Nair et al, [13])</td>
<td>r = 0.741 (p&lt;0.01)</td>
</tr>
</tbody>
</table>

Attempt of Sen & Mukhopadhyay, 2008, has its novelty from a number of points of view. The test is found constructed in view of a number of essential psychometric considerations. Even in case of selecting multiple choice options, the detailed analysis of distracter was done. The seven sub-dimensions considered in the test were related to essential primary mental abilities upon which learners’ basic knowledge and understanding in physics depend. Item construction seemed perfect and the process as well as product aspect of knowledge in physics might be given due emphasis. Analysis of the factor structure emerged two factors viz. process factor and product factor (results of construct validity: Table II) indicating that learners’ might use their process skill and product skill both for solving the items of the test. Therefore students’ score of this test probably indicates in what way they use information known already, as well as, in what way they process those in learning. Hence, the test has possibility to predict their future accomplishment in learning physics accurately, hence seem to be a true aptitude test. For estimating reliability and validity a number of criteria were used. Even and exhaustive factor analysis was done to estimate construct validity of the test. This advanced statistical technique, whereas was not used in a number of the other related tests.

Conclusion

The detailed review reveals that though aptitude in physics is a major area of concern of educators, but the available tests are extremely inadequate in number. The test of Sen & Mukhopadhyay, 2008 is psychometrically sound, the dimensions are operationally well defined, and are standardized in view of a number of rational criterion. The standardization was done on
the basis of the response of 703 students of a particular state in India the sample size could be made more including students of some other states also in order to provide a more appropriate norm. In the test, only one norm was prepared. But different norms as per gender, locality etc. may also be established. After all, a longitudinal study may also be conducted to estimate more accurately how far the test could predict future success of learners. In spite of these scopes of further improvement, the test can be used conveniently by teachers in a physics class room (a detailed manual is available) to explain the result of students’ success or failure in class examinations or as a criterion of selection in case of admissions. Researchers working in the related field of science education may also use it as a tool. Further study may be conducted in view of the suggestions.

References


